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Forest Possibilities of Aspen Lands in the Lake States

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The first season's field work in Minnesota, resulting in the collection of data on 83 plots, was done by E. E. Probstfield, with the help of student assistants, G. E. Sargent and F. G. Whitney. E. T. Erickson and F. G. Whitney assisted in the second season. The Wisconsin Conservation Commission and its field personnel in northwestern Wisconsin, particularly Rangers Henry Freund and Ray Hassett, rendered valuable assistance. L. M. Wood assisted in the analysis of the data. Raphael Zon, Director of the Lake States Forest Experiment Station, was a never-failing source of encouragement and inspiration. To all these, the authors wish to express their grateful acknowledgment.

FOREST POSSIBILITIES OF ASPEN LANDS IN THE LAKE STATES

JOSEPH KITTREDGE, JR., and S. R. GEVORKIANTZ

THE PROBLEM

Enormous Area of Aspen Lands

The most characteristic sight in traveling through northern Minnesota and Wisconsin is the monotonous and scrubby looking growth of small aspen trees. Actual surveys indicate that the aspen, often somewhat mixed with paper birch, is the most abundant and wide-spread type of forest vegetation in the northern Lake States. In St. Louis County, Minnesota, Hansen (1923) found that it occupied 70 per cent of the cut-over land. In northern Wisconsin the soil types on which aspen grows abundantly represent more than 50 per cent of the total forest area. In Menominee County, Michigan, the Land Economic Survey finds 34 per cent of the forest area in aspen. Even in the northern part of the Lower Peninsula of Michigan, which is usually thought of as a region of jack pine and scrub oak, the Survey figures indicate one third of the area in aspen. The extensive field work in this study of aspen, chiefly in northern Minnesota and northwestern Wisconsin, led to estimates, confirmed by the figures cited, that the aspen lands in northern Michigan occupy about one third and in northern Wisconsin and Minnesota almost two thirds of the total forest area. This represents a land area of about 21 million acres. The enormous size of this area in itself constitutes a major problem of land use.

Agricultural Development Slow

Improved farm land in the northern part of the Lake States increased from 1910 to 1924 at the rate of about 250,000 acres a year. Considering that clearing and settlement are advancing northward, where climatic and economic conditions for farming are progressively less favorable, and that many of the settlers who have tried to make a living on these northern areas have been disillusioned; and, furthermore, that the importance of growing timber crops on large areas of these lands is being recognized, it seems unlikely that the rate of settlement will increase for some time in the future. Considerable portions of the land on which aspen grows are suitable for farming after they are cleared. On the assumption that the proportion of increase in improved farm land of the aspen type will correspond to the proportion that type is of the whole area of forest land (60 per cent), the rate of clearing is not likely to exceed 150,000 acres a year. At this rate, the clearing of 21 million acres of aspen lands would require about 140 years. Even if taken up at a more rapid rate, the area that will remain in aspen is enormous.

Altho aspen is characteristic of fertile soils, large areas of the aspen type, owing to their rough and rocky character, will never be suitable for farming. The largest single area of this kind is the triangular region north of Lake Superior, in Minnesota. A large part of the 21 million acres, therefore, may be expected to produce at least one and probably two or three crops of aspen before it will be needed for agriculture.

Present Limited Use of Aspen

The use of aspen in the region where it grows or to which it can be shipped profitably is extremely small in comparison with the amount that is or soon will be available. The census (1927) of 1926 reported only 33,000 cords used for pulpwood. Possibly 15 million board feet are used annually for excelsior and lumber. Crocker (1926) estimated the consumption of aspen in 1925 as 173,000 cords in the three Lake States. An unknown amount, which may easily amount to 50,000 or 100,000 cords, is used by settlers for firewood and poles. The total present yearly consumption of aspen in the Lake States is estimated, therefore, to be between 175,000 and 250,000 cords.

Aspen is used chiefly for paper pulp, excelsior, boxes, heading, pails, staves, lumber, and fuel. In Europe and also in Japan it is extensively used and highly valued for matches. This use may develop gradually in this country also. Similarly, the utilization for excelsior, box boards, and lumber may increase, altho there is no immediate prospect of a rapid increase. For paper pulp, aspen reduces readily by the sulphite or the soda process and yields pulp of excellent color, that bleaches easily (Wells and Rue, 1927). Actually, little aspen is being used in the sulphite process. Considering the concentration of paper mills in the Lake States, particularly in eastern Wisconsin, and the diminishing supplies of spruce, balsam fir, and hemlock, consumption of aspen for paper pulp may increase considerably. This increase, however, will not come immediately (1) because much hemlock will be available for the next 10 years from the lumbering operations of northern Wisconsin and Michigan, and (2) because the use of large proportions of apsen will require costly modifications in the manufacturing processes at most of the existing paper mills. The present limited use of aspen, therefore, is likely to continue without marked change for another 10 years, after which its consumption may be expected to rise at an accelerating rate.

Will Consumption Keep Pace with Potential Production?

If the present consumption of aspen is about 200,000 cords a year and probably will not exceed 250,000 in the next 10 years, how do these figures compare with the amount of aspen already available or that will become merchantable in 10 to 20 years? The stand of aspen in the Lake States in 1928 may be estimated at 30 million cords. At a rate of consumption of 250,000 cords a year, this is enough for more than 100 years. These 30 million cords represent the stand on about 4 million acres. There remain 17 million acres of small growth, much of it well stocked, that is growing at the rate of about one sixth of a cord per acre per year. The amount of aspen, therefore, is increasing a little less than 3 million cords a year. In 20 or 30 years the annual growth will probably double, or become 6 million cords. The growth each year at these rates will supply the present demand for 12 to 24 years. Even if the estimates of area, stand, and growth are high, the conclusion is still unquestionable—that consumption of aspen is not keeping pace with the growth. Moreover, there is little prospect that the growth will be utilized for many years. Agricultural development will require only a fraction of the aspen lands. What then, is to be done with these millions of acres to obtain the best use and highest value from them?

Natural Conversion to Pine or Spruce

A desirable solution of the problem of the use of the aspen lands would be the replacement of aspen by other more valuable species, as spruce or pine. The process is going on naturally and slowly over limited areas. Observations lead to the estimate that not more than 20 per cent of the aspen land in the northern Great Lakes region as a whole has an appreciable representation of more valuable tree species coming up with or under the aspen. This estimate is confirmed by figures from the survey of St. Louis County, Minnesota, by Hansen (1923), in which he found 24 per cent of the cut-over area, most of which was aspen and paper birch, to contain from 10 to 60 per cent of conifers in mixture. St. Louis County forms a part of northeastern Minnesota, where the conifers, particularly balsam fir, are most commonly represented in the aspen stands. The estimates in the field study for this section placed the percentage of aspen with a mixture of conifers at 30. The greater proportion of conifers in this region, however, is counterbalanced by the wide areas in other parts of Minnesota and Wisconsin where they are not found on aspen lands.

Moreover, the areas on which spruce, pine, or other conifers are found with aspen are increasing slowly, perhaps even decreasing. The slow increase is due (1) to the fact that logging and fires have left only occasional and scattered trees of pine or spruce from which seed might blow to reseed the aspen lands. (2) The limited supply of seed from the few scattered seed trees is not more than enough to feed the many hungry squirrels, mice, and other rodents, which devour most of it before it germinates. (3) The seeds are carried only limited distances from the seed trees and when the trees are few and far between they reseed only a small part of the total area. These are ample reasons why the reseeding of aspen lands to conifers is progressing slowly. To make matters worse, large areas of aspen lands burn over in the frequent bad fire seasons. A fire is almost certain to kill all the young conifers in its path. While the effectiveness of efforts to protect the forest lands from fire is increasing, the area burned annually, which amounted to 381,000 acres on the average in the years from 1916 to 1925, may easily account for the destruction of small conifers on a larger area of aspen land than was reseeded in the same time. As fire protection improves, the rate of natural conversion to pine and spruce will undoubtedly increase, but the progress will be slow for at least 50 years. After that many of the present small pines and spruces or those that will become established in the next few years will reach seed-bearing age and will in turn scatter seed to convert additional areas to more valuable kinds of forest.

Can Aspen Lands Be Made More Valuable?

There is little prospect that aspen by itself will soon become more valuable. At present, it is worth little or nothing except on areas near a manufacturing plant that uses aspen. Similiarly, the oversupply for several years promises to be valuable only on the areas favorably located with respect to markets. White and Norway pine, however, are now worth $8.00 to $12 a thousand board feet, and white and black spruce, $3.00 to $5.00 a cord. Balsam fir is less valuable, altho it is much used for pulpwood and lath. The demand for spruce and pine is generally strong and is increasing as the supply is decreasing. There is every reason to believe, therefore, that the pines and spruces will become more valuable. If the aspen lands can be made to produce spruce or pine, the conversion will almost certainly increase the value of those lands, even if the future values of pine and spruce should not be higher than the present.

The conifers do not reach merchantable size as soon as the aspen, but their greater value may more than offset the greater cost of growing them. It may also pay the cost of conversion by planting seedlings of spruce or pine and raising them to maturity.

Certain questions may well be asked by those who own or are interested in the northern cut-over lands where aspen is so common. How much will aspen yield at different ages? At what ages or sizes should it be cut? Does it pay to grow aspen? Is the aspen being replaced naturally by more desirable species? Can the conversion be hastened by silvicultural treatment? If not, can it be accomplished by seeding or planting? Under what conditions will the conversion of aspen to pine or spruce pay?

In an attempt to answer these questions, 305 areas were examined carefully in 1925 and 1926, chiefly in Minnesota and northwestern Wisconsin. On 123 areas data were taken to show the growth and yield of well stocked aspen; on 17, the growth of paper birch; and on 165 the natural conversion of aspen-birch to conifers. Seven hundred and seven aspen trees were cut and analyzed as the basis for volume tables already published (Cloquet, 1926). One hundred and sixteen paper birch trees were analyzed and from the measurements the volume tables for paper birch in the appendix were prepared. The answers that will be suggested to the foregoing questions should be applicable to conditions in northern Minnesota, northern Wisconsin, and probably also in both parts of northern Michigan.

HISTORY OF THE ASPEN FOREST

The uplands of the northern Lake States region were originally forested chiefly with pine, spruce, balsam fir, hardwoods, and hemlock. Aspen occurred either in small patches where fires had burned, or as scattered trees in the old-growth forest.

It formed merely an inconspicuous part of the brush in the forest. However, careful inspection of all tree species in the remaining old-growth forests usually reveals aspens. It was found in 3 of the 10 pine stands counted by Morbeck (1922) in northern Minnesota. It forms an understory in places in the old white pine forest of the Chippewa National Forest, as mentioned by Truax (1915) and observed by others. From one to 35 per cent of "poplar," doubtless mostly aspen, was found in the white spruce areas by Kenety (1917). It is a frequent constituent, altho an inconspicuous and unimportant one, in the northern hardwood-hemlock forests, as shown by Frothingham (1915). Aspen was, therefore, widely distributed in the northern Lake States before logging began. The thousands of acres of aspen in nearly pure stands, which are so characteristic of the region now, have developed almost entirely within the last 70 years.

Result of Cutting and Fires in Original Forests

In the early days of logging in the old-growth pine forests, only the largest and best trees were cut. Gradually, as the value of lumber increased, smaller and poorer pines were taken. As the stands of white pine became harder to find, the best of the white pine was culled from the mixtures of white and Norway pine and of white pine and hardwood-hemlock. More recently, Norway pine and hardwood-hemlock became valuable and heavy cuttings removed all the trees down to 10 or 12 inches in diameter. A large proportion of the smaller trees that were left was destroyed or damaged in logging. The white pine forests that had been cut lightly for the best trees were gone over again, and most of the remaining timber was removed. In the process, most of the small aspens were cut off or broken.

Aspen stumps do not sprout, but the wide-spreading roots give rise to new stems, called suckers. Fires have the same effect as cutting.

Origin of Pure Stands of Aspen

Fires that burned through the old pine slashings destroyed all living trees in their path, with the occasional exception of a big thick-barked pine. The small pines, spruces, balsam firs, and aspens were destroyed. The pines and spruces did not sprout but the aspen suckers came up promptly and vigorously and were many times more numerous than were the aspen trees in the old stands.

Much of the cut-over land burned several times within the 10 or 20 years following cutting. The repeated fires even more completely destroyed existing trees (Fig. 1). After every fire, however, aspen suckers came up more abundantly and more extensively. Seedling aspens, on the contrary, are rare because few aspen seed trees were left, and conditions were generally unfavorable to germination and establishment. The present large area of nearly pure stands of aspen is due largely to its ability to produce many suckers from the roots for every tree that is killed by logging or fire.

Origin of Mixed Stands of Aspen and Conifers

White pine, spruce, or balsam fir seedlings were usually on the ground as advance growth under the old stands. More than 21,500 white pine seedlings to the acre were found in a stand of old-growth white pine in northwestern Wisconsin. In northern Minnesota, Morbeck (1922) found from 1,300 to 16,000 white pine seedlings to the acre under old-growth white pine stands. Cutting destroyed only part of this young growth. Fires destroyed all of it wherever they burned. Occasional areas and patches, however, escaped the fires and on these areas the pines and spruces left after logging have lived and grown. The aspen came up from suckers after cutting on the same areas and, as its early growth is much more rapid, the aspen has usually formed an overstory with pine, balsam fir, and spruce as an understory. In this way a considerable part of the larger conifers in mixture with the aspen originated.

Some defective or small trees of pine, balsam fir, and spruce were left in the early logging. Those that survived produced seed, the result being scattered seedlings and irregular patches under the aspen on some of the burned-over areas. Wind storms and repeated fires, however, have destroyed much of this source of coniferous seed in most parts of the region. On the whole, mixed stands of aspen and conifers are not common or extensive.

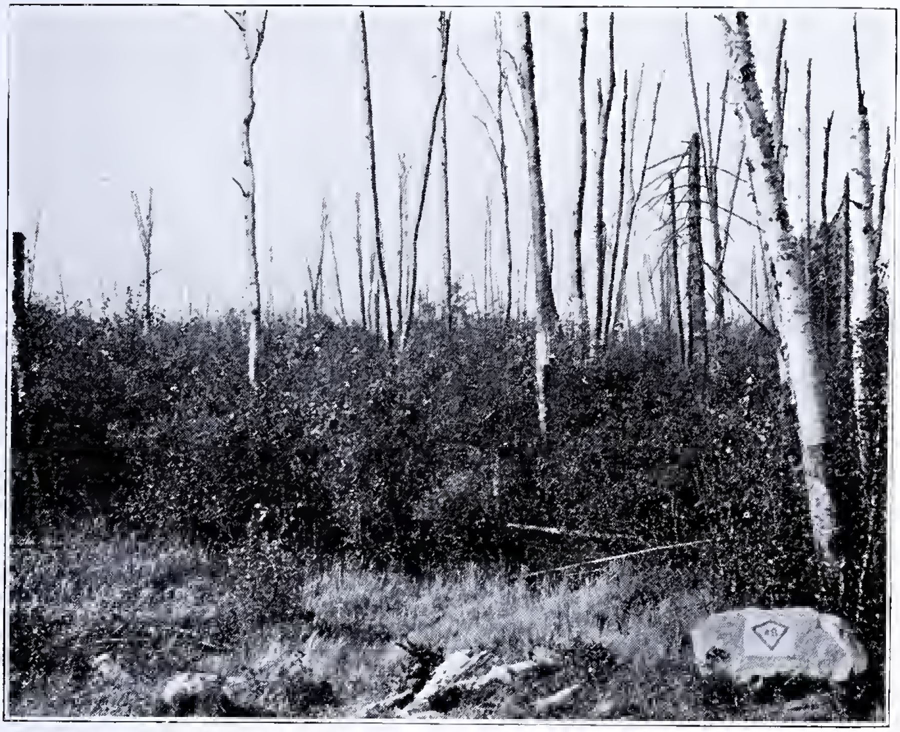

Fig. 1. Aspen-Paper Birch Land Approximately Five Years After Fire "Brush." St. Louis County, Minn.

DESCRIPTION OF THE ASPEN FOREST

Species of Aspen and Their Ranges

The species that makes up the bulk of the aspen forest in the northern Lake States is the true aspen *(Populus tremuloides)*, commonly known as popple. It grows from Labrador to Hudson Bay and Alaska, throughout the Lake States, and as far south as Illinois and northern Missouri. Sometimes mixed with the aspen but much more often in separate patches, the large-tooth aspen *(Populus grandidentata)* is found, altho much less commonly, throughout the region except in southwestern Minnesota. A third species is the balsam poplar *(Populus balsamifera)*, sometimes called poplar or Balm-of-Gilead, which is also found in the northern half of Minnesota, Wisconsin, and Michigan. The aspen is much the most abundant of the three species and altho they have many similarities of habit, the material presented in this report will refer to the true aspen unless otherwise specified.

Associated Species

Altho most of the aspen forest appears to be wholly or predominantly aspen, other species occur commonly in mixture with and usually subordinate to it. Paper birch,[1] often called white birch, is the most common and most conspicuous of the associated species. Over small areas or in patches the birch may outnumber the aspen or even occur in pure stands. This is frequently true around lake shores, where, it has been suggested, the predominance of birch may be due to the harvesting of the aspen by beavers. The largest aggregate area where paper birch predominates is the strip of land draining into Lake Superior along its north shore, in Minnesota. Elsewhere and more commonly birch is found mixed with aspen as a more or less suppressed understory of small, poorly developed birches, which may be even more numerous than the aspens. The suppressed birches are usually as old as the aspens and have persisted, altho unable to keep pace with its rapid height growth during the first few years. Seedlings or young saplings of paper birch are rarely found under older aspens, except one-year-old seedlings, which sometimes start abundantly on rotten wood but rarely survive.

Other species associated with aspen in the order of their abundance are balsam fir, white pine, white spruce, black spruce, sugar maple, red maple, Norway pine, jack pine, elm, red oak, bur oak, black ash, green ash, yellow birch, basswood, jack oak, pin cherry, ironwood, and tamarack. Of these, only balsam fir, pine, spruce, and sugar maple are sufficiently numerous to have any importance. Jack and Norway pine are found with aspen only where there are openings in which they have been able to maintain themselves, and on the drier, sandier soils. The other species form more or less important parts of an understory on areas where fires have not burned repeatedly. The larger trees were present as advance growth or germinated from seed scattered shortly after the aspen started. Balsam fir is the only one that has aggressively seeded under the aspen stands. White pine and the spruces have also seeded in to a limited extent, but ordinarly only small seedlings are to be found.

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[1] The scientific names of trees and plants mentioned in the text will be found in the appendix.

Occurrence of Aspen

Aspen grows on a wide variety of soils, in fact, on almost any of the soils in the northern part of the region except the driest and sandiest, which are occupied by jack pine. Figure 2 shows the general areas in which aspen predominates in Minnesota and Wisconsin. Ordinarily, it is not found in the swamps on peat soils, altho one area was measured on which the aspen was growing well on peat more than 5 feet deep. If the soils are grouped according to the surface geological formation, aspen is found on all except the coarser sands of glacial outwash and the shallowest soils of the rock outcrops. It grows abundantly on sandy moraines, clay moraines, till, both sandy and clayey lake-wash till, and lake-bed clays. It was found most commonly in this study on sandy moraines and on till. If the soils are grouped according to texture, aspen was found on sands that are well supplied with moisture or underlaid not too deeply by a layer of finer soil, on fine sands, sandy loams, fine sandy loams, silt loams, clay loams, and even clay along the south shore of Lake Superior—most commonly on sandy loams and fine sandy loams.

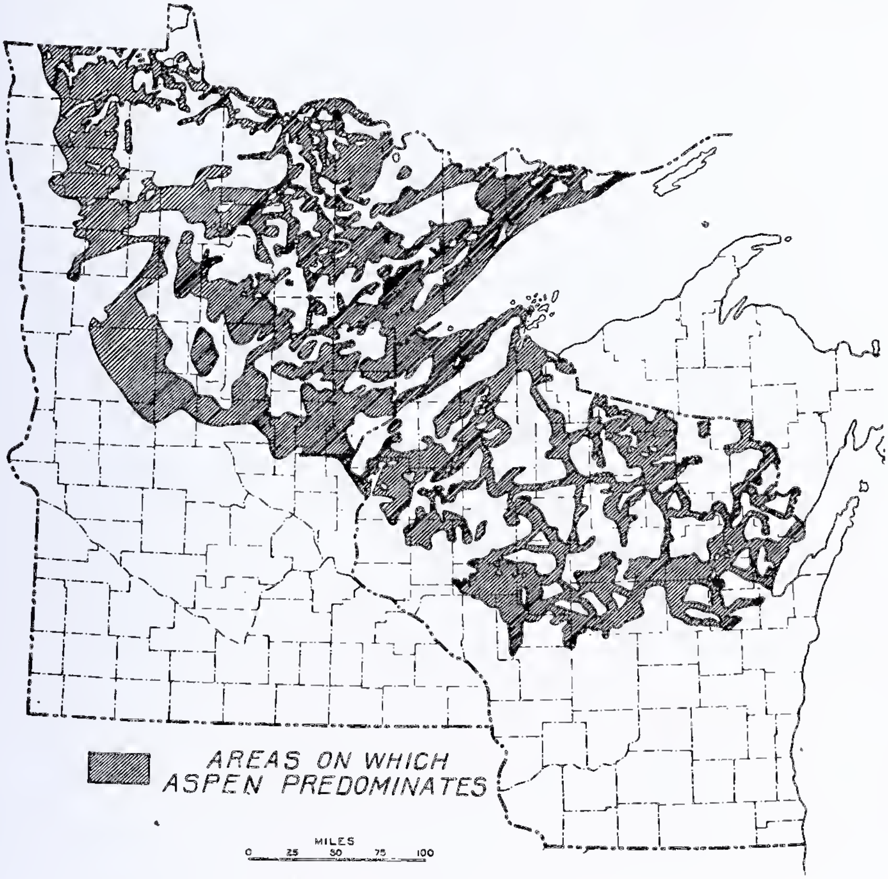

Fig. 2. Areas on Which Aspen Predominates

A species that thrives on such widely differing soils is evidently not exacting in its requirements. The only soil limitation is found in the deep, medium, or coarse sandy soils, which are least retentive of moisture and low in their content of nitrogen, lime, and other nutrients. These sandy soils are characterized by less than 10 per cent of silt and clay, less than 0.03 per cent of nitrogen, less than 0.2 per cent of lime, and a minimum moisture content for the existence of plants,[2] about 2 per cent or less. Organic matter may be as low as one per cent. Acidity may vary from extremely acid, with a pH as low as 4.3, to slightly acid or neutral, with pH 7.

Sites

The rate of growth and the yield of aspen at any given age vary with the productivity of the soil or, as it is more commonly known in forestry, with the quality of site. Site quality may be defined and indicated in several ways. The most satisfactory, based upon the aspen forest itself, is the arbitrary classification of the stands by a numerical value for what is called the site index. This is simply the average total height of the dominant trees in a stand at 50 years old, or the height that the average dominant tree in a younger or older stand would have at 50 years. The dominant trees are those whose crowns extend above the general level of the forest canopy and receive full light from above and partial light from the side. They are larger than the average trees in the stand and have well developed crowns. Altho the crowns may be crowded on the sides, these trees have had ample space to develop as compared to other trees in the stand. For the determination of site index, moreover, they should be trees whose height growth has not been affected by cuttings, fire, or damage of any kind. The curves in Figure 3 represent the site indexes for aspen at different ages.

In order to determine the site index for a given stand, it is necessary to average the heights of at least 5 and preferably more dominant trees on each acre. For example, in a 30-year-old stand, 5 dominant trees are found to be 35, 38, 40, 36, and 32 feet high. The average dominant height is, therefore, 36 feet (Fig. 3). By following perpendicularly along the line from 30 on the scale of age until it crosses the horizontal line from 36 on the scale of height of average dominant tree, the intersection comes about one-tenth of the distance below the curve of 50 toward the curve of 40. The difference between 50 and 40 is 10, and one-tenth of this is one, so the site index for this 30-year-old stand with an average dominant height of 36 feet is 50 minus one, or 49 feet. The site index of any stand may be obtained in the same way.

These site indexes correspond with what is known of the productivity of the different soils on which aspen grows. For example, the medium to coarse sandy soils of outwash plains or sandy moraines, which are drouthy and low in nutrients, usually have site indexes below 55, except where the soil is close to swamp or ground water level. The fine sandy soils of outwash plains, the clay and clay loam soils around the shores of Lake Superior, and the shallow sandy loam soils on the rock outcrops in northeastern Minnesota belong also to site index classes less than 55. The site index classes above 67 include the silt loam soils, except those shallowly underlaid by rock; the fine sandy loam soils on bowlder clay or clayey moraine or on the heavier soils of old lake beds and those not too shallowly underlain by rock; and the fine sandy soils on bowlder clay. The other groups of soils on which aspen was found are in the intermediate site index classes, between 55 and 67.

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[2] Technically this is known as the hygroscopic coefficient.

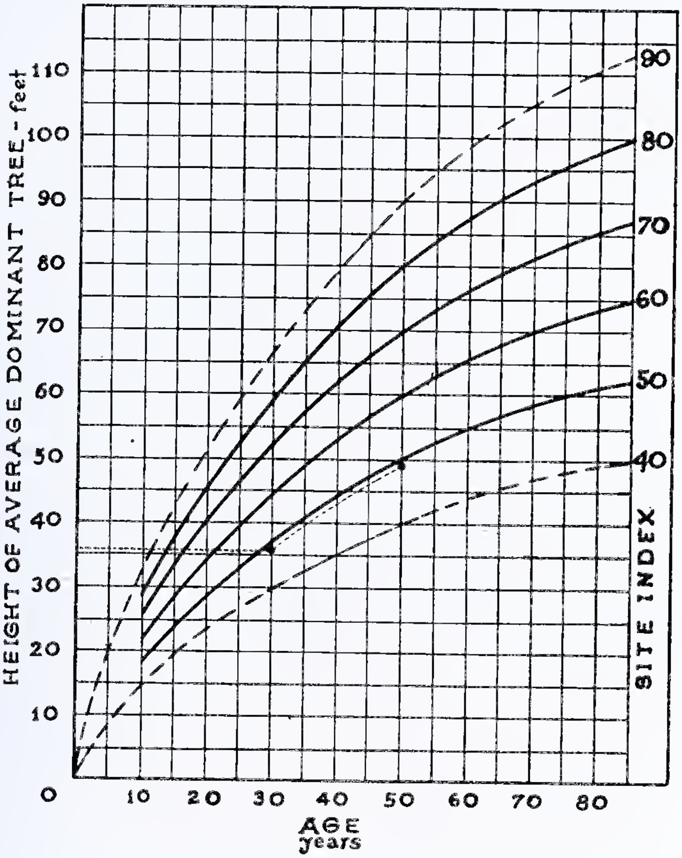

Fig. 3. Site Index Curves for Aspen

A general statement of the geographical distribution of the good and poor sites is impossible, because the glacial soils of the region, and hence the sites, are inextricably intermingled within short distances. Certain large areas with predominantly good and poor sites for aspen may be mentioned. Poor sites, with indexes less than 55, are characteristic of the hilly, gravelly moraines that occupy a large area in Vilas and Oneida Counties, in north central Wisconsin, and a strip of similar topography from Aitkin through Cloquet and northeastward into Lake County, in Minnesota. The red clays and clay loams along Lake Superior, chiefly on the Wisconsin shore from Superior to Port Wing and south of Washburn and Ashland, are also poor sites; the areas of loam and silt loam soils of northwestern Itasca County and of Beltrami County southeast of Red Lake, in Minnesota, are excellent sites with indexes generally above 67.

Another means of judging the fertility of the soil and of checking the site index for aspen is the brush and ground cover under the aspen. Many kinds grow commonly on all soils on which aspen is found; others are limited to certain site index classes. Mountain maple, dogwood, alder, clintonia, pyrola, arbutus, raspberry, bedstraw, starflower, baneberry, clubmoss (except ground pine), ferns (except brake), hepatica, meadow rue, Canada mayflower, choke cherry, viburnum, bellwort, dwarf raspberry, wild ginger, currant or gooseberry, mitrewort, and twisted stalk, usually indicate site indexes of 53 or higher. Sweet fern indicates a site index of less than 47. Blueberry, ground pine, and wintergreen indicate site indexes less than 60.

The associated tree species also give a check on the site indexes. Ash, hop-hornbeam, northern white cedar, balsam poplar, bur oak, and basswood are found chiefly on sites with indexes above 57. Yellow birch and elm usually occur on those with indexes above 60. Black spruce and Norway pine rarely occur on sites with indexes higher than 64, and scarlet and jack oak are usually on those with indexes less than 55.

In estimating the growth of stands of aspen, the correct determination of the site index, or quality of site, is important. It is worth while to estimate the site quality by all three of the ways suggested and to check one against the other, because sometimes the relation between the average height of the dominant trees and their age, alone, may not be a reliable index. Altho neither the vegetation nor the soil alone can be relied upon for an accurate appraisal of site quality, the combination of the two may be more reliable than the site index figure alone. For example, on one plot the average height of dominant trees was 35 feet at 34 years of age, which corresponded to a site index of 44. Viburnum, clintonia, wild ginger, twisted stalk, and bedstraw indicated a site equivalent at least to that represented by site index 55. On the other hand, blueberry indicated that the index was unlikely to be more than 58. The soil corresponded to that of site index 58. In this case, the low height was probably due to the fact that the aspens had been more or less suppressed by old-growth pines, which were cut 5 years previously. The soil and plant indicators checked one another and made possible the correction of a site index figure that was seriously low.

The site index classification is used for the division of the aspen growth and yield figures according to the productivity of the sites. Five 10-foot site index classes cover the range of sites on which aspen was found growing. These classes, beginning with the best, are 80, 70, 60, 50, and 40. By far the larger proportion of the aspen stands is found in classes 70, 60, and 50. Class 60 contained the largest number of the measured plots and undoubtedly includes the average for the region as a whole. It is sometimes difficult to think of the productivity of the soil or the quality of site in terms of these site indexes. It may be helpful, therefore, to remember that site index 60 indicates a site of average quality, 70 and over one of good quality, and 50 and under one of poor quality.

As there are large differences in the yields of aspen on the different sites, it is important to know not only the site index for a specific stand but also what proportion of the aspen type is growing on the poorer sites, on which it may never reach merchantable size. A classification into corresponding site indexes of the surface formations on which aspen was found by Hansen (1923) showed that in St. Louis County, Minnesota, about 20 per cent of the aspen is growing on sites of index less than 55. Twenty-two per cent of the well stocked plots in this study were found in classes 40 and 50. This percentage is probably high, because in selecting plots for the yield tables an attempt was made to obtain as many as possible of those representing both the extremely low and the extremely high site indexes, which occur less commonly and are harder to find than those of average quality. Of the plots selected to illustrate the development of conifers with the aspen and that were chosen without respect to density or site quality, 17 per cent were on site indexes less than 55. It is likely, therefore, that between 15 and 20 per cent of the aspen in the northern part of the Lake States occupies the poorer sites, represented by site indexes less than 55.

These quality classes, which are most easily recognized by the site indexes, or the relation between height and age of the dominant trees, are also distinct for well stocked stands in respect to the other factors measured in determining the volume and growth of forests. With occasional exceptions, the higher the site index for stands of the same age, the higher are the other factors, namely, basal area of stand, volume, average height, average diameter, and average annual growth per acre. The only factor that does not increase as the site index increases is the number of trees per acre. As the site index increases the number of trees per acre decreases, because the trees on the better sites grow larger and can not stand so close as the smaller trees on the poorer sites. These relationships become clearer by reference to Tables I, II, and III.

TABLE I

YIELD TABLE OF WELL STOCKED ASPEN IN TREES ONE INCH AND OVER IN DIAMETER AT BREAST HEIGHT

Total cubic feet

Age	Av. total height of dominant trees	Av. height of trees	Av. diameter at breast height	No. of trees per acre	Basal area per acre	Total peeled volume per acre	Av. annual growth	No. of plots
years	feet	feet	inches		sq. ft.	cu. ft.	cu. ft.	
Site index 80 feet at 50 years								
20	46	36	3.3	1,490	88	1,540	77	—
30	59	50	4.8	880	110	2,550	85	1
40	71	62	6.3	600	129	3,650	91	—
50	80	74	8.1	400	143	4,720	94	1
60	87	84	10.3	265	153	5,620	94	—
70	93	91	12.6	185	161	6,290	90	—
80	98	96	14.3	148	165	6,780	85	—
								2
Site index 70 feet at 50 years								
20	40	34	2.9	1,800	83	1,340	67	7
30	51	46	4.2	1,065	102	2,180	73	5
40	62	57	5.4	760	120	3,160	79	4
50	70	68	7.0	495	133	4,060	81	2
60	76	76	9.0	330	144	4,840	80	3
70	82	82	10.9	235	151	5,420	77	3
80	86	86	12.6	180	155	5,750	72	1
								25
Site index 60 feet at 50 years								
20	34	29	2.5	2,300	76	1,080	54	6
30	44	40	3.5	1,400	94	1,760	59	17
40	53	49	4.5	980	110	2,450	61	8
50	60	58	5.9	645	122	3,220	64	12
60	66	65	7.6	422	133	3,820	64	13
70	70	70	9.3	295	139	4,290	61	—
80	74	74	10.6	234	143	4,600	57	—
								56
Site index 50 feet at 50 years								
20	29	23	1.9	3,200	60	710	36	5
30	37	32	2.7	1,910	75	1,170	39	4
40	44	39	3.5	1,300	88	1,620	41	4
50	50	47	4.6	856	98	2,140	43	4
60	55	52	5.8	580	105	2,520	42	3
70	59	57	7.1	400	109	2,820	42	—
								20
Site index 40 feet at 50 years								
20	23	19	1.3	4,100	38	360	18	—
30	29	27	1.9	2,420	46	600	20	1
40	35	33	2.4	1,660	54	850	21	2
50	40	39	3.2	1,110	60	1,100	22	—

TABLE II

Yield Table of Well Stocked Aspen in Trees 6 Inches and Over in Diameter at Breast Height

Board feet (International Rule, ⅛ inch kerf.*)

Age	Av. total height of dominant trees	Av. height of trees	Av. diameter at breast height	No. of trees per acre	Basal area per acre	Volume per acre	Av. annual growth	No. of plots
years	feet	feet	inches		sq. ft.	bd. ft.	bd. ft.	
Site index 80 feet at 50 years								
30	59	64	6.4	228	50	5,700	190	1
40	71	68	7.0	365	101	12,800	320	—
50	80	74	8.3	369	138	21,200	423	1
60	87	84	10.3	265	153	30,000	500	—
70	93	91	12.6	185	161	37,500	535	—
80	98	96	14.3	148	165	41,800	522	—
								2
Site index 70 feet at 50 years								
30	51	63	6.0	170	33	3,800	126	5
40	62	66	6.7	319	80	9,200	230	4
50	70	70	7.6	403	124	16,700	334	2
60	76	76	9.0	320	143	23,700	395	3
70	82	82	10.9	235	151	30,100	430	3
80	86	86	12.6	180	155	34,800	435	1
								18
Site index 60 feet at 50 years								
30	44	59	6.1	80	14	1,400	47	17
40	53	60	6.3	215	45	5,000	125	8
50	60	62	6.9	358	96	10,700	214	12
60	66	66	7.9	378	127	16,500	275	13
70	70	70	9.3	290	138	21,300	304	—
80	74	74	10.6	234	143	24,800	310	—
								50
Site index 50 feet at 50 years								
40	44	53	6.1	74	13	1,400	35	4
50	50	54	6.4	200	42	4,500	90	4
60	55	55	7.0	306	81	8,200	136	3
70	59	59	7.6	327	102	11,500	164	—
								11

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* Stump height, one foot; top diameter inside of bark, 5 inches. Bark is not included in volume.

TABLE III

YIELD TABLE OF WELL STOCKED ASPEN IN TREES 7 INCHES AND OVER IN DIAMETER AT BREAST HEIGHT

Board feet (Scribner Decimal C Rule*)

Age	Av. total height of dominant trees	Av. height of trees	Av. diameter at breast height	No. of trees per acre	Basal area per acre	Volume per acre	Av. annual growth	No. of plots
years	feet	feet	inches		sq. ft.	bd. ft.	bd. ft.	
			Site index 80 feet at 50 years					
30	59	70	7.5	79	24	1,400	46	1
40	71	73	7.9	216	74	5,700	142	—
50	80	77	8.7	304	124	14,200	284	1
60	87	84	10.4	255	149	23,300	388	—
70	93	91	12.6	185	161	29,900	426	—
80	98	96	14.3	148	165	32,900	411	—
								2
			Site index 70 feet at 50 years					
30	51	69	7.3	35	10	500	17	5
40	62	70	7.6	167	52	3,400	84	4
50	70	72	8.1	297	105	9,600	192	2
60	76	77	9.3	290	137	17,300	288	3
70	82	82	10.9	235	151	23,600	338	3
80	86	86	12.6	180	155	27,400	342	1
								18
			Site index 60 feet at 50 years					
40	53	65	7.5	68	21	1,000	25	8
50	60	66	7.7	213	69	4,300	86	12
60	66	68	8.3	300	112	10,300	172	13
70	70	71	9.5	268	132	16,400	234	—
80	74	74	10.6	229	140	19,700	246	—
								33
			Site index 50 feet at 50 years					
50	50	58	7.4	68	20	1,000	20	4
60	55	59	7.6	174	55	3,200	53	3
70	59	60	8.0	240	84	6,600	94	—
								7

* Stump height, one foot; top diameter inside of bark, 6 inches. Bark is not included in volume.

For example, a comparison of 50-year stands having site indexes of 70 and 50 shows average heights of 68 feet and 47 feet; average diameters of 7.0 inches and 4.6 inches; average basal areas of 133 square feet and 98 square feet; average volumes of 4,060 cubic feet and 2,140 cubic feet; average annual growth of 81 cubic feet per acre and 43 cubic feet, but only 495 and 856 trees per acre.

Each site index class is divided into 10-year age classes from 20 to 80 years. The aspen forests, like plants and animals, increase in height, in diameter, in basal area, and in volume per unit area as they increase in age, and the increases are more rapid in the high site index classes than in the lower. The number of trees per acre, however, decreases rapidly as the stands grow older and the smaller, weaker trees are killed out in the struggle with their larger, stronger neighbors for light, water, and nutrients. On the average site, this reduces the number of trees per acre from 2,300 at 20 years to 295 at 70 years.

Composition of the Stand

In every forest and in any stand, there are trees of different sizes. In aspen forests, which are usually composed of trees of approximately the same age, the trees of average size are most numerous, and the number both larger and smaller than average becomes progressively smaller. In the 55-year age and 62-foot site index classes in well stocked stands, the average is 495 trees to the acre, distributed among the diameter classes as follows:

Diameter breast high in.	No. of trees per acre	Diameter breast high in.	No. of trees per acre
4	7	8	119
5	42	9	52
6	109	10	12
7	154	Total	495

The distribution of sizes varies at different ages and on different sites, but tends to follow the same general scheme. The largest number of trees are of average size and those larger and smaller than average decrease progressively.

The principal value in knowing the number of trees of different sizes is in the knowledge of the number of trees that, because they are above certain diameters, are usable for commercial purposes. For most uses at the present time aspen becomes merchantable when it is 6 or 7 inches in diameter. The numbers of trees per acre of these sizes and larger at each age and in each site index class are shown in the yield tables for board foot contents in trees 6 inches and over (Table II), and in trees 7 inches and over (Tables III).

The number of aspens per acre varies widely in stands of the same site and age. These variations are often referred to as differences in degree of stocking, or density. They may be due to one cause or a combination of causes—the origin of the stand, whether from seedlings or suckers; the number and intensity of fires that may have killed a part of the trees; or the use for grazing, which thins out the young trees.

This variation in number of trees per acre may be illustrated by figures from a large number of measured stands of different densities. The number of trees per acre 6 inches and more in diameter, in the plots less than 50 years old, commonly vary as much as 150, both above and below the average number in well stocked stands for any given age and site, as shown in Table II. Expressed in another way, the actual stands deviated 75 per cent above and below the average for well stocked stands. The stands more than 50 years old, almost without exception, had less than the average number of trees 6 inches and more as compared with well stocked stands. Several plots had 150 trees per acre less than the well stocked stands, and in some cases even 250 or 300 less. As an example, the average well stocked stand at 40 years with site index 60 (Table II) has 215 trees 6 inches and over in diameter to the acre; yet stands of this age and site were found to have from 350 to 50 trees. If all trees of one inch and over are included, the well stocked stands had 980 to the acre; the average on those not selected to represent good stocking was about 700.

The density, or degree of stocking, as judged by the number of trees to the acre, is also influenced by the proportion of other species—pine, balsam fir, or spruce—that may be mixed with the aspen. These usually occur as an understory of small trees. If they are numerous the stocking is more dense than if it were judged by the number of aspens alone. The stands that were more than 40 per cent overstocked were those in which the overstocking was due to an understory of conifers. This effect on the density of the mixture of smaller conifers was also illustrated by stands that were 75 per cent understocked with aspen but were overstocked when all species were included.

The number of trees per acre has been commonly used as the basis for classification. Hansen (1923) considered "normal" or well stocked stands of seedlings to have from 1,000 to 2,000 stems to the acre, from 800 to 1,500 saplings, and from 500 to 800 poles. On this basis he found the following percentages of aspen-paper birch stands in the normal, overstocked, and understocked groups for each of the three size or age classes:

Size class	Normal per cent	Overstocked per cent	Understocked per cent
Seedlings	28	15	57
Saplings	45	27	28
Poles	38	48	14

His standard for normal, or well stocked, stands is lower than that used in this study, as is indicated by a comparison of his figures—500 to 800 trees per acre in the pole stage representing an average age of 30 years with the density of 1,400 trees to the acre in well stocked stands on an average site at 30 years, in Table I. Allowing for the predominance of seedling stands that he found, and combining seedling, sapling, and pole stands for both aspen-birch and aspen-birch mixed with conifers, about 45 per cent of the area of aspen-birch type in St. Louis County, Minnesota, is occupied by understocked stands.

The Michigan Land Economic Survey assigned the forest areas to classes of good, medium, and poor stocking. The classes were not defined by number of trees per acre, but good stocking included stands that would yield good grades of merchantable timber. For the aspen-birch area in the counties of Antrim, Roscommon, Alpena, Ogemaw, and Menominee, in a part of the region where the aspen stands are generally spoken of as poor and scrubby, they found 76 per cent of good stocking, 17 per cent of medium stocking, and 7 per cent of poor stocking. Their sample acres in Ogemaw County show 560 trees at 10 years, 1,410 at 15 years, and 870 at 27 years. These densities would not justify their inclusion with the well stocked plots used for the yield tables.

The survey of the Wisconsin Land Economic Inventory in two townships of southern Bayfield County indicates about 35 per cent of the aspen-paper birch type fully stocked, 30 per cent medium, and 35 per cent sparsely stocked. That a large part of the aspen area is well stocked may be explained and confirmed by the fact that fires, which have been so prevalent and are so large a cause of the extensive areas of aspen in the region, do not decrease but rather increase the density of the new crop of aspen. On the whole, probably about a third of the total aspen area in the region has a sufficient number of trees to the acre to be considered well stocked for growth; not more than a fourth is so poorly stocked that it will not produce a merchantable stand at maturity.

GROWTH AND YIELD

Well Stocked Stands

Well stocked stands contain a sufficient number of trees well distributed over the area to form a nearly complete crown canopy (Fig. 4). These stands, because of a more or less uniform spacing of the trees and an equal start, produce at a given age and on a given site a large percentage of the total number of trees of about average diameter. Stands of this character produce high yields.

The development of well stocked aspen stands in respect to average height, diameter, basal area per acre, and yield per acre for the 40, 50, 60, 70, and 80 site index classes and for 10-year age classes, are shown in Tables I, II, and III. Table I gives figures for total yield in cubic feet of all trees one inch or more in diameter; Table II, the yield in board feet of trees 6 inches and more in diameter by the International Log rule; and Table III the yield of trees 7 inches and more in diameter, by the Scribner Decimal C rule. The tables also show the average annual growth per acre for each age and the average total height of the dominant trees, which is used in determining the site index. Table IV contains figures on the yield per acre in cords of 8-foot wood

Well stocked stands in which the trees average 6 to 8 inches in diameter will produce 50 cords per acre in 40 years where the site index is 80; 55 cords in 50 years where the site index is 70; 44 cords in

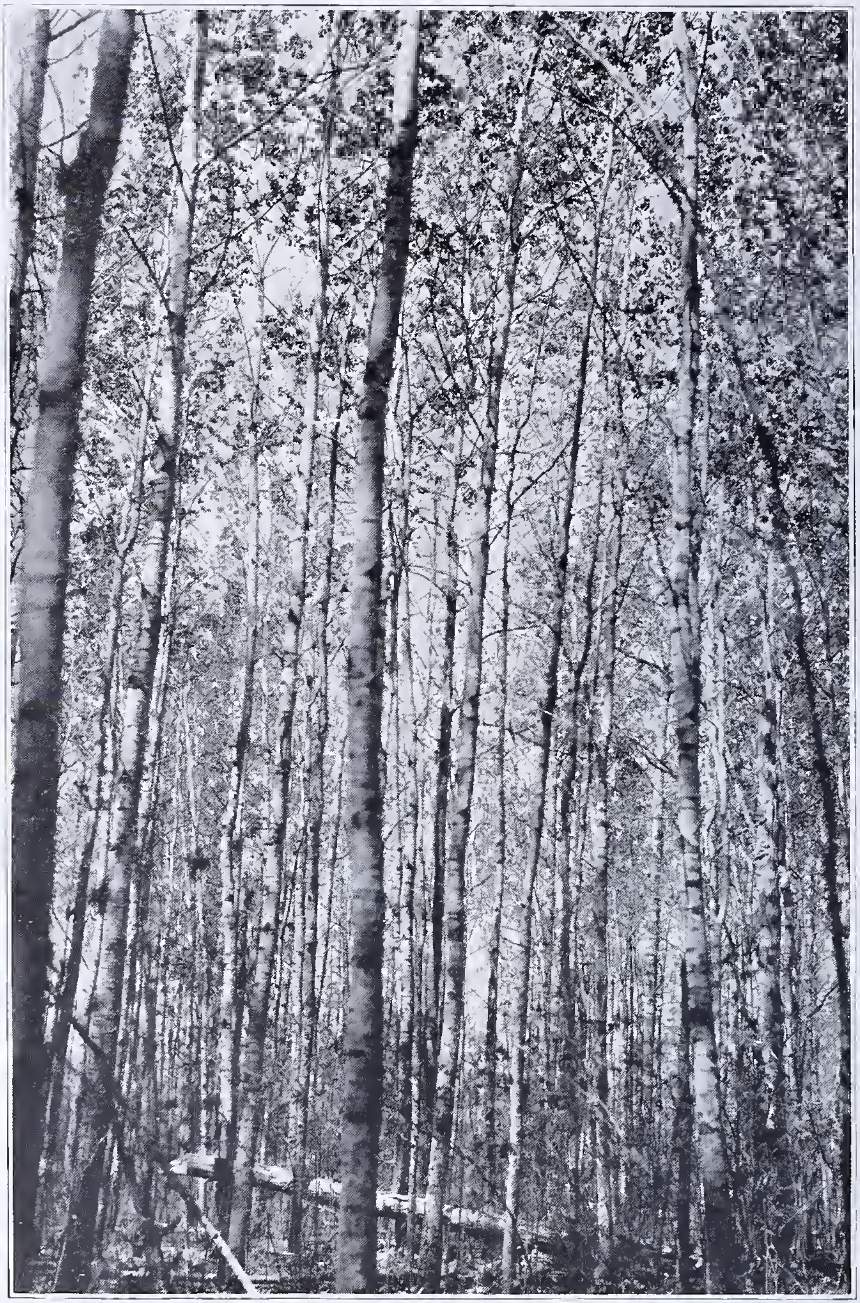

Fig. 4. Well Stocked Aspen 40 Years Old

Experimental cutting areas seeded to white pine and white spruce. Chippewa National Forest, Minnesota.

50 years where the site index is 60; and 33 cords in 60 years where the site index is 50. The mean annual growth at 50 years on the average site represented by site index 60 is 64 cubic feet, about 9/10 cord per acre. On the good sites the growth at the same age may be 94 cubic feet, or 1¼ cords, and on the poor sites even in well stocked stands the

growth is only from 22 to 43 cubic feet, or 1/10 to 1/2 cord per acre per year, respectively.

TABLE IV

Cordwood Yields for Well Stocked Aspen in Trees 4 Inches and More in Diameter at Breast Height

Age	Av. total height of dominant trees	Av. diameter at breast height	Basal area per acre	Peeled volume per acre*	Av. annual growth per acre
years	feet	inches	sq. ft.	cords†	cords†
Site index 80 feet at 50 years					
20	46	3.3	88	9	0.45
30	59	4.8	110	32	1.07
40	71	6.3	129	50	1.25
50	80	8.1	143	63	1.26
60	87	10.3	153	71	1.18
70	93	12.6	161	76	1.08
80	98	14.3	165	80	1.00
Site index 70 feet at 50 years					
20	40	2.9	83	5	0.25
30	51	4.2	102	25	0.83
40	62	5.4	120	43	1.07
50	70	7.0	133	55	1.10
60	76	9.0	144	63	1.05
70	82	10.9	151	67	0.96
80	86	12.6	155	69	0.86
Site index 60 feet at 50 years					
30	44	3.5	94	12	0.40
40	53	4.5	110	30	0.75
50	60	5.9	122	44	0.88
60	66	7.6	133	51	0.85
70	70	9.3	139	55	0.79
80	74	10.6	143	57	0.71
Site index 50 feet at 50 years					
40	44	3.5	88	11	0.27
50	50	4.6	98	26	0.52
60	55	5.8	105	33	0.55
70	59	7.1	109	37	0.53
Site index 40 feet at 50 years					
50	40	3.2	60	5	0.10

* Stump height, one foot; top diameter inside of bark, 3 inches.

† Standard cord 4x4x8 feet, close piling. Volumes in cords were obtained by applying the factors used for conversion of merchantable volumes in cubic feet to cords to corresponding average diameters at breast height. As a check, the same results were obtained from curved distributions of stems of different sizes per acre for a given age. The latter curves were also used for obtaining volumes in cords for stands with average diameter less than 4 inches.

Altho the data from which the growth figures were derived were taken largely in Minnesota and northwestern Wisconsin, they are probably applicable also to aspen stands throughout the northern part of Michigan and of Wisconsin. This is confirmed by the few stands measured in Marquette County, Michigan, by the data of the Land Economic Survey in Ogemaw County, Michigan, which indicate site index 56 and good stocking; and by figures for Antrim County, Michigan, by Buttrick (1923), which indicate mean annual growth at 30 and 38 years of 2/3 to 1 1/10 cords per acre per year. It is interesting to note for comparison that Schotte (1916) found stands of the closely related aspen in Sweden producing 1½ to 2 cords per acre per year. The latter figure exceeds the most rapid growth found in the Lake States, which was 1 7/10 cords per acre per year in a 50-year stand in Lake County, Minnesota.

Several important conclusions may be reached by a study of the yield table figures. If the trend of diameter growth in Table IV, site index 40, were extended, it would be found that the trees would not reach an average merchantable size for pulpwood (about 6 inches) until 80 years. The average annual growth on these poor sites is only 1/10 cord per acre. Moreover, the rot in aspen on an average site increases rapidly after 60 years and amounts to 20 per cent of the volume of the trees at 70 years, according to Schmitz and Jackson (1927). It seems probable that the decay will be as serious on poor sites as on average sites, if not more serious. Therefore it is inadvisable to plan to grow aspen on these sites until they are 70 or 80 years old, because they may not survive to those ages. On the other hand, if the aspen is cut at 50 years the trees will average less than 4 inches in diameter. It may be concluded, therefore, that the growing of aspen for pulpwood on lands of site index 40 and probably also on those of site indexes less than 50, will result in disappointment or failure.

For the possible production of aspen lumber, Table III, showing the board feet in trees 7 inches and more in diameter by the Scribner Decimal C rule, is a conservative guide. On site index 80, well stocked stands should produce 14,200 board feet at 50 years; on site index 70, 9,600 board feet at 50 years; and on site index 60, 10,300 board feet at 60 years. The yields for these comparatively small trees, by the Scribner Decimal C rule, are notably low for mills that saw carefully and utilize closely the small material. The following comparison of the yields in board feet at 50 years by the Scribner rule (Table III) with those by the International rule (Table II), which includes also the 6-inch trees, shows the conservatism of the Scribner figures.

Site index	Scribner	International
80	14,200	21,200
70	9,600	16,700
60	4,300	10,700

On site index 40, aspen will not produce enough trees more than 6 inches in diameter to provide an appreciable yield. On site index 50, at 70 years, it will produce only 6,600 board feet, by the Scribner rule. Even this amount would have to be discounted by at least 20 per cent for decay. As with cordwood, therefore, it is not likely to be profitable to grow aspen for lumber on site indexes less than 55.

Where paper birch predominates in mixture with aspen or occurs in almost pure stands, the growth and yield figures for aspen are not directly applicable. In order to indicate the development, growth, and yield of paper birch, areas were selected from the 38 that were measured to represent relatively pure and well stocked paper birch stands. The figures are given in Table V. The average dominant height on these areas corresponded to aspen site indexes between 50 and 60. In general, paper birch on corresponding soils has a lower site index value, grows more slowly, and yields less at the same age than aspen. This is indicated by the fact that paper birch plots, as a whole, may be represented by a site index of about 53—the average for the aspen plots was 64. In other words, the average dominant tree at 50 years in a paper birch stand would be 53 feet high; aspen on the same area would be 64 feet. If the yields at 55 years and site index 60 are compared, paper birch would produce 38 cords to the acre and aspen 47 cords in well stocked stands.

TABLE V

Yield of Relatively Pure, Well Stocked Paper Birch Stands, with Average Dominant Height Corresponding to Site Index Classes 50 and 60 of Aspen

Age, years	Site index class			
	50		60	
	No. of trees 6 inches and more	Av. number of cords per acre	No. of trees 6 inches and more	Av. number of cords per acre
30	10– 30	8		
40	50–100	15	150–250	25
50	150–250	21	300–400	35
60	200–350	26	300–400	40

Volume tables giving the contents of standing trees of paper birch in total cubic feet, merchantable cubic feet to a 3-inch top diameter, and cords were prepared from analyses of 116 paper birches and are included in Tables XVIII, XIX, and XX, in the appendix.

Understocked Stands

The density, or number of trees per acre, which has been discussed, is not the most reliable index of stocking for use in the prediction of growth or yield of aspen, because the relation between changes in number of trees per acre and increase in volume as the stands grow older is not consistent. Better measures of the degree of stocking are afforded by basal area, total volume, or average annual growth per acre. Basal area, or the sum of the areas of the cross-sections of the stems of the trees at breast height reduced to an acre basis, is the simplest measure to compute and to use. It was used as the criterion of stocking in the preparation of the yield tables and in comparisons of understocked and overstocked with well stocked stands. The relation between increase in basal area and in volume is sufficiently definite that changes in basal area may be used for rough predictions of changes in volume.[3]

In preparing yield tables, which include columns of basal area per acre, plots were eliminated that were less than 69 per cent[4] stocked as compared with the average for each 10-foot age and 10-foot site index class. The areas measured without regard to good stocking of aspen were more than 25 per cent understocked by basal area of aspen in 93 out of 144 cases, or 65 per cent. If conifers are included in the basal area, only about 8 per cent of the plots were understocked by as much as 25 per cent. It is estimated that in comparison with the averages for well stocked stands given in the yield tables, two-thirds of the area of the aspen-birch forest is understocked and grows less rapidly in volume than is indicated in the yield tables.

Understocking may cause a serious inaccuracy in the prediction of growth by the use of the yield tables. Altho only a few areas examined were less than 50 per cent stocked, the use of yield tables on these areas can not be recommended. A wide difference is obtained between the well stocked stands on which the yield table is based and the poorly stocked stands. For example, a 34-year-old stand was found on a site indicated by the average height of the dominant trees to have an index of 44, and the basal area, the number of trees, and the volume were all below that given by the yield table for this age and site index. The basal area was 35 square feet, only 56 per cent of the 63 square feet given in the yield table. There were only 170 aspens per acre that were one inch and more in diameter, as compared with the normal of 1,880, or only 9 per cent. In volume, the stand had 405 cubic feet, 42 per cent of the 960 cubic feet given by the yield table. Such a comparison clearly shows the danger of applying yield tables based on well stocked stands to poorly stocked stands.

A further indication that yield tables are unsuitable for stands like the example given is that open growing trees usually form large, bushy crowns at the expense of their growth in height, so their average dominant height is not a true index of the site. For instance, the site index of 44 for the stand described is low. The soil and vegetation showed that the true site index for this area would have been at least 58, if the stand had been fully stocked. The effect of understocking on the height growth and, therefore, the site index in badly understocked stands, may often be difficult to detect, hence the use of the yield tables as a basis for predicting growth by basal area in stands more than 50 per cent understocked is not recommended.

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[3] This method neglects relatively small differences in the stands caused by changes in form and height.

[4] The ± 31 per cent deviation from good stocking represented twice the standard deviation of the distribution of the plots about the mean.

Understocking may be evident, also, in its effect on the size of the average tree in the stand as well as on the number of trees, basal area, and volume per acre. Usually the average tree is larger in an understocked stand than in a well stocked stand of the same age and site index class. For example, one plot 66 per cent stocked by basal area and only 25 per cent by number of aspens one inch and more in diameter per acre, had an average diameter of 8.9 inches as compared with 6.4 inches for the well stocked stands of corresponding age and site. This relationship is sometimes reversed, but not often. The high yields of fully stocked stands are due in no small degree to the large number of trees per unit of area.

The use of yield tables for the prediction of growth involves (1) the determination of the age of the stand and of the site index from the relation between the average height of the dominant trees and the age. The site index should be checked by noting the other species of trees and the ground cover associated with the aspen and by the character of the soil. (2) An inventory should be made from representative strips or sample areas to show the number of trees per acre of different diameters. From this inventory the basal area per acre may be determined by the use of tables of basal area or areas of circles. (3) The computed basal area should then be compared with the basal area for the same age and site index class as shown in the yield table and the percentage calculated of the actual stand as compared with the well stocked stand. (4) The volume that a well stocked stand would have at 10, 20, 30, or more years in the future may be obtained from the tables. Multiplying this figure of future volume by the percentage of actual present stocking by basal area, an indication of the yield of the understocked stand for 10, 20, or 30 years in the future will be obtained. An example will make the calculation clearer. Plot 15 was found to be 27 years old and had a site index of 70. Its basal area from measurement of the diameters of the trees was 73.5 square feet. The well stocked basal area for site index 70 and 27 years (Table I) is 97 square feet. The stand is therefore 76 per cent stocked. It is desired to know what this stand may be expected to produce when it is 50 years old. The volume of a well stocked 50-year stand on site index 70 is 4,060 cubic feet. Multiplying 4,060 by 76 per cent gives 3,086 cubic feet, the predicted volume of the stand after 23 years, when it becomes 50 years old.

The calculated future yields of understocked stands obtained in this way are usually less than actual yields, because as the more open stands grow older, fewer trees are crowded out and the trees grow more rapidly in diameter than in fully stocked stands. This method of predicting yields is reliable and its conservatism may often be desirable to compensate for unforeseen damage or losses.

Overstocked Stands

Overstocking may be defined in several ways. The most definite, altho an arbitrary way, is by comparison with the basal areas of well stocked stands in the yield table (Table I). The degree of overstocking may then be measured by the percentage by which the basal area of a given stand exceeds that of the yield table for the corresponding age and site index. Stands having not more than 31 per cent greater basal area than the average of the well stocked stands were included in the preparation of the yield tables. Overstocked stands may therefore be considered to include only those that have more than 31 per cent excess of basal area. This is undoubtedly a higher limit for overstocking than was set by Hansen (1923); consequently many stands classified by him as overstocked would not be so classified according to this standard.

Another approach may be made by considering that overstocking, to have any significance, should be indicated by measurable stagnation of growth in diameter, volume per acre, or height. Depression of height growth would lower the site index. Only one stand was found in which the apparent stagnation, from observation in the field, was confirmed when the measurements were worked up. In this case the height of the dominant trees at 36 years indicated a site index of 50. On this basis the plot had 71 per cent excess basal area. The vegetation and soil, however, showed conclusively that the site index should have been at least 62—overstocking had reduced it by 12 units. Additional evidence of error in the site index was provided by the number of trees per acre, which, in a stand so heavily overstocked by basal area, would be expected to be decidedly higher than the yield table value. Actually it was lower. This indicated that the stand belonged to a higher site index class, because the number of trees per acre decreases as the site index increases. Furthermore, the average tree was one inch larger in diameter than the yield table value for that age and site index. This again suggested a higher site index, because the average tree in an overstocked stand would ordinarily be smaller than the yield table average. The reassignment of this stand to site index 62 reduced the degree of overstocking from 71 per cent to 29 per cent and made consistent the relationship to the well stocked stands in number of trees per acre and in size of average tree. This effect of overstocking in reducing the height growth and consequently the site index may cause serious discrepancies in all comparisons with the yield table and in predictions of growth. As it is not easy to detect, all available means should be used to check the determination of site index figures derived from the average dominant heights. Fortunately, overstocking to a degree that will cause a serious depression of the site index is probably uncommon and limited to small areas.

The measured plots included only three that had more than 31 per cent excess of basal area as compared with the yield table. Excluding the one just cited, the other two, altho they had 34 and 35 per cent excess of basal area, respectively, showed no evidence of stagnation.

The stands that had more than 25 per cent excess of basal area show that this degree of overstocking, or 40 per cent excess in number of trees per acre as compared with the yield table, does not cause stagnation but results in proportionately higher yields. For example, a stand 47 years old with site index 69 had a basal area per acre of 178 square feet, or 38 per cent above the 129 square feet of the yield table. The plot had 800 trees above one inch in diameter to the acre as compared with the well stocked average of 570, a 40 per cent excess. There were 532 trees 6 inches and more in diameter per acre as compared with 390 for the well stocked stand. The total volume was 5,082 cubic feet per acre, 35 per cent above the normal of 3,760. The size of the average tree, however, was only 6.2 inches—a little less than the normal of 6.4. Both the basal area and the number of trees per acre clearly suggest the possibility of stagnation due to overstocking; yet the total volume and the average annual growth per acre of 108 cubic feet are as much in excess of the yield table value as are the figures for basal area or number of trees. The conclusion seems justified that overstocking in aspen to an extent sufficient to cause stagnation of growth is extremely rare, and is usually not operative even in stands that appear to be too dense for their best development.

MATURITY, ROTATION, AND LONGEVITY

The maturity of a forest may be determined technically by finding the age at which the average annual growth culminates and overtakes the current annual growth. On the average site for aspen the average annual growth culminates at about 50 years, when it amounts to 64 cubic feet per acre. The current annual growth for 10-year periods reaches a peak of 77 cubic feet per acre between 40 and 50 years and declines until it is exceeded by the average annual growth at about 50 years. This is a desirable age at which to cut the stands, provided the trees have reached sizes suitable for commercial utilization.

Rotation is a term used to express the approximate age at which forest stands will be cut. With aspen, a rotation of 50 years for site index classes 60, 70, and 80 corresponds to the age of maturity or maximum average annual volume growth, and also provides a high yield of trees more than 6 inches in diameter suitable for pulpwood, box boards, or small saw timber. In site index class 50, the trees do not reach an average diameter of 6 inches until after they are 60 years old. The rotation, therefore, would usually be not less than 60 years. On the poorest sites, represented by index class 40, it is doubtful whether aspen stands will survive long enough to become marketable.

For merchantable saw timber, a rotation of 60 or 70 years will usually be necessary. The average annual growth does not culminate until the stands are 70 years old or older. The longer rotations for saw timber are advisable only in the site index classes of 80, 70, and the upper part of 60.

After 60 years the average annual growth declines, owing to the death of the crowded trees. The larger trees in the stands, however, continue to increase in diameter until they become 100 years old or even a little older. The oldest well stocked stand measured was 85 years old, on site index 72. It had an average diameter of 12½ inches, and a maximum diameter of 17 inches. A patch of aspen that had come up in an opening in the old-growth pine forest before it was cut was 95 years old, 100 feet high, with trees up to 18 inches in diameter. Occasional trees are found as large as 20 inches in diameter. However, stands of aspen more than 75 or 80 years old are rare and have little importance.

Influence of Decay in Forest Management of Aspen

The development of decay in aspen was studied by Schmitz and Jackson (1927). By applying their figures of the average percentage of intermediate and final decay on an average site (site index 60) at different ages to the average annual volume growth from the yield table, the following figures of reduced or net annual growth are obtained.

Age, years	Av. gross annual growth cu. ft.	Decay, per cent	Av. net annual growth cu. ft.
40	61	7.7	56
50	64	11.2	57
60	64	15.7	54
70	61	20.5	49

The percentage of decay up to 50 years is not large enough to change materially the culmination of the average annual growth, which comes at about 50 years for net as for gross growth. The increasing rate of decay after 50 years emphasizes the advantage of harvesting aspen by that age wherever the trees are large enough to make their exploitation economically practicable. Furthermore, it shows that rotations of 70 years or more, such as would be required to grow aspen to merchantable size on poor sites, are inadvisable. Occasional stands as old as 75 years, however, have less than the average percentage of decay and produce good yields of saw timber. A good example is the stand 75 years old with site index 78 that was cut on the Chippewa National Forest for box boards in 1924 and 1925. This stand had less than 5 per cent of serious decay.

The question whether decay is more serious on poor sites than on good sites has not been answered. There is a general impression among those familiar with the region that the aspen goes to pieces earlier from decay or some other cause on poor sites than on good sites. This impression is confirmed by the distribution of the measured plots in relation to age and site index. In spite of the fact that a special attempt was made to obtain data representative of all the age and site index classes, none of those with site index less than 50 were more than 45 years old, those of site index between 50 and 55 were less than 60 years old, and the few plots over 74 years old had site indexes over 65. Schmitz and Jackson (1927), however, suggest from data regarding the prevalence of decay in trees of different sizes that the quality of site makes little or no difference. This question can not be answered satisfactorily until more definite evidence is available.

Summarizing the subject of maturity and rotation, it may be said that aspen will produce good yields of pulpwood in 50 or 60 years on site indexes higher than 55, and that stands on site indexes above 60 may often be grown to 70 years for the production of saw timber. On the other hand, aspen on site indexes less than 50 will probably never produce a merchantable crop of timber before a large proportion of the trees becomes unmerchantable from decay or other causes. An intermediate group of stands on site indexes between 50 and 55 may be grown to produce pulpwood on a rotation of 60 years, but can not safely be held for longer rotations to produce saw timber.

REPRODUCTION OF ASPEN

Aspen reproduces so abundantly by suckers that its seeding habits are comparatively little known. The "cotton" is produced in great quantities in most years by the female trees. Locally, however, only one in 30 of the trees may bear seed. One tree 1½ inches in diameter and 11 feet high had 213 catkins with an average of 22 fruit capsules on each catkin. With several or many seeds from each catkin, the seed production from a mature stand would evidently be enormous. The seeds mature about May 15 and fall from then until early in June. For this brief period the air may be full of the cotton and the ground covered with a mat of it. The small size of the seed and its fitness for wide distribution by the wind is indicated by the fact that there are

2½ to 3 million of the seeds to a pound. A large proportion of the seeds, however, at least in some years, do not mature. The viability of fresh fertile seeds is high but lasts not more than two or three weeks after they are mature. Germination begins within 12 hours after the seeds fall and is complete within a week if conditions are favorable.

Seedlings

In spite of the enormous production of aspen seed, the number of seedlings in most years is small. Apparently, seedlings start abundantly only in the occasional year in which good rains occur and the ground is thoroly moist during the brief period while the seeds are falling and retain their vitality.

The distribution of seed in effective quantities for long distances is illustrated by a stand, apparently of seedling origin, in northern Michigan. Seven years after a heavy cutting in an old-growth forest of sugar maple, there are on the average 2,218 aspens to the acre, averaging 16 feet in height and far overtopping the still more abundant reproduction of maple. Careful examination of the remaining old-growth forests adjacent does not reveal any aspen and apparently the numerous aspen seedlings originated from seed trees at a considerable distance from the area.

In general, however, so many of the seedlings die, even when seeds have been abundant, that the reproduction of aspen from seed is comparatively unimportant, especially in the production of a complete stand in the first generation. The abundant production and wide distribution of the tiny seeds are extremely important, however, in accounting for the extensive range of aspen and the small number of poorly developed trees in many stands of other forest types. In the northern Lake States seeding has been much less important in the creation of the millions of acres of aspen forest than has regeneration by root suckers.

Suckers

The preponderance of aspen forest in even-aged well stocked stands on areas known to have been burned repeatedly, is strong evidence of the part played by fires and of subsequent suckering. The vigorous growth of young trees the first year after cutting or fire would hardly be possible for aspen seedlings and affords further evidence of the origin of the stands.

The roots form a network of horizontally spreading laterals that are always within 2 feet and frequently within a few inches of the surface (Baker, 1923). The suckers develop from parts of the roots within 6 inches of the surface, after cutting or fire that kills the trees. Several suckers may come from the same root. Figure 5 shows a root of aspen 24 years old from which two suckers started where the root passed over a rock ledge and was covered by only a layer of leaf litter. The stems of the two suckers were 15 years old, that is, they started when a previous 9-year-old stand was killed by fire. The small roots that come off the main root near the suckers are from 9 to 12 years old and illustrate the characteristic formation of new roots near the point where each sucker develops. The specimen shown in Figure 5 was obtained in northeastern Minnesota; the point where the suckers came up was 10 or 12 feet along the root from the parent tree.

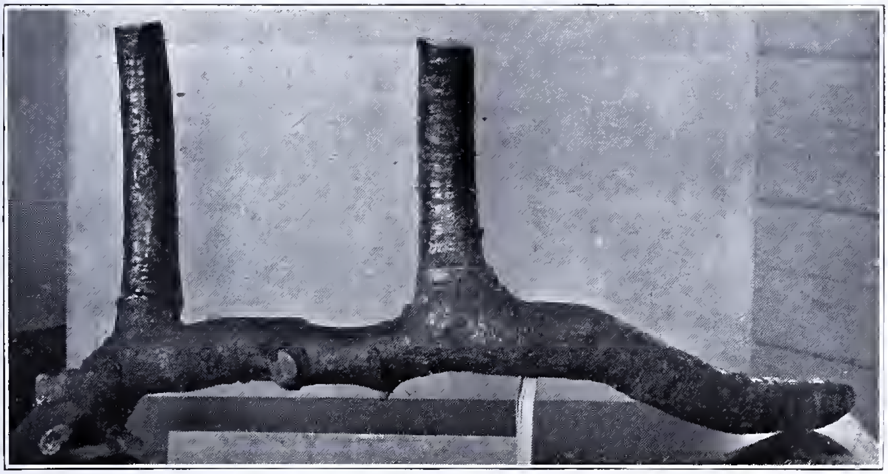

Fig. 5. Stems of Two Aspen Suckers, 15 Years Old, from Foot 23 Years Old, with Branch Roots 9 to 12 Years Old
Specimen loaned by courtesy of T. S. Hansen.

The number of suckers in the first one to 3 years after cutting or fire is large, and decreases rapidly as the trees grow older and the competition between them becomes more intense. Baker (1923) found more than 85,000 suckers to the acre at the end of the first year after spring cutting. The number decreased in the second and third years. The Dominion Forest Service, on experimental plots at Petawawa, Ontario, found that the number of suckers increased from the first to the third years after cutting and then decreased. On an experimental area in the Chippewa National Forest, cut clear in May, 19,060 suckers per acre were found at the end of the first year. Weigle and Frothingham (1911), working in Maine, found that after the ninth year dominant suckers in good condition were found only in stands of crown densities of 0.3 or less.

In the stands examined in Minnesota and Wisconsin that had produced any considerable number of suckers as a result of light fires or low density, the number of suckers increased with the age of the parent stand from 30 years to a maximum at 70 years, and then decreased as the vigor of the parent stand declined. The maximum number of suckers found per acre was 4,500 in a 70-year-old stand that had 170 aspens more than one inch in diameter to the acre. Even at 95 years, one stand had 2,300 suckers of recent origin to the acre.

The relation of the number of suckers to the density of the parent stand is less well marked than the relation to age. The number of suckers decreases and rarely exceeds 600 to the acre in stands that have more than 250 trees to the acre. Two exceptional cases were found, however, in one of which a stand of 420 trees had 1,200 suckers to the acre, and in the other, a stand with 700 trees to the acre, 50 years old, had 150 suckers. The number of suckers increases as the number of trees in the parent stand decreases below 250 to the acre. In stands of 150 trees, about 1,000 suckers to the acre were found on the average and in those of 100 trees, about 1,200 per acre. A 39-year-old stand on an experimental area in the Chippewa National Forest had, before cutting, from 137 to 1,020 suckers per acre. This indicates that in well stocked stands 40 to 65 years old with more than 250 trees to the acre there are from one to 3 suckers for each large tree. After cutting 292 out of 424 trees, or 69 per cent, 4 suckers for each cut tree came up the first year. After cutting 233, or about half the trees, 27 suckers per tree came up. After clear cutting of the 640 trees per acre, 30 suckers per tree developed the first year.

General conclusions as to relationships between suckering and age, density, season and degree of cutting, and fire in the parent stand can not be drawn from the limited data available, but the data are ample to show the tremendous capacity of the aspen stands to regenerate themselves by suckering after cutting or fire.

MANAGEMENT OF PURE ASPEN AS A PERMANENT CROP

A large part of the aspen in the northern Lake States consists of comparatively well stocked stands, most of them less than 20 years old, but with considerable areas up to 40 or 50 years old and already of merchantable size. Allowing for some poor stocking, these stands over considerable areas should produce from 10 to 30 cords to the acre at 40 to 50 years of age, or even more on the medium and good sites, represented by site index 55 or over.

In order to carry the younger unmerchantable stands to maturity, protection from fire is essential. Even a light fire kills many of the aspens and indirectly causes the early death of most of those that may survive for a few years. If the object of management is to obtain a new crop of aspen after cutting, it is only necessary to cut all the merchantable material; the new crop of suckers will provide ample and prompt regeneration.

The cost of growing aspen is low. It establishes itself without cost. Land values on the rocky or stony soils and on the better soils in the northern parts of the region that are not yet needed for agricultural development, are or should be not more than $1.00 or $2.00 an acre. If taxes are assumed to be 10 cents per acre per year, fire protection 3 cents, and the yield 20 cords to the acre in 40 years, the crop of aspen will earn 6 per cent if it has a stumpage value when cut of $1.93 per cord. It will earn 5 per cent if it has a value of $1.39. If on a poorer site, where it requires 50 years to produce 20 cords to the acre, it will earn 5 per cent if the stumpage value is $2.41. Prices of standing aspen, sold in 1926 in Minnesota for cordwood, ranged from 25 cents to $1.00 per cord, with an average of 75 cents; and for lumber, from $1.00 to $3.00 per 1,000 board feet, with an average of $2.25 (Wackerman, 1926). It is not unreasonable to anticipate that aspen 20 or 30 years in the future will have values of $1.50 to $2.50 per cord. Tables VI and VII show the future stumpage values that aspen must have to earn 3, 4, 5, or 6 per cent interest under different combinations of taxes, yields, and rotations. For any company or owner who has a use or a market for aspen, its management as a crop for pulpwood is not unattractive.

TABLE VI

ASPEN STUMPAGE VALUES PER CORD AT 40 YEARS

Yield per acre, cords	Annual taxes plus 3 cents fire protection, per acre					
	8 cents	13 cents	18 cents	23 cents	33 cents	43 cents
			To earn 3 per cent			
5	$2.11	$2.86	$3.62	$4.37	$5.88	$7.37
10	1.06	1.43	1.81	2.19	2.94	3.69
20	0.53	0.72	0.91	1.09	1.47	1.84
30	0.35	0.48	0.60	0.73	0.98	1.23
			To earn 4 per cent			
5	3.04	3.99	4.95	5.89	7.79	9.68
10	1.52	2.00	2.47	2.94	3.89	4.84
20	0.76	1.00	1.24	1.47	1.95	2.42
30	0.51	0.67	0.82	0.98	1.30	1.61
			To earn 5 per cent			
5	4.35	5.55	6.75	7.98	10.38	12.80
10	2.17	2.78	3.37	3.99	5.19	6.40
20	1.09	1.39	1.69	1.99	2.59	3.20
30	0.72	0.93	1.12	1.33	1.73	2.13
			To earn 6 per cent			
5	6.18	7.74	9.28	10.83	13.93	17.03
10	3.09	3.87	4.64	5.41	6.97	8.52
20	1.54	1.93	2.32	2.70	3.48	4.26
30	1.03	1.29	1.55	1.80	2.32	2.84

TABLE VII
Aspen Stumpage Values per Cord at 50 Years

Yield per acre, cords	Annual taxes plus 3 cents fire protection, per acre					
	8 cents	13 cents	18 cents	23 cents	33 cents	43 cents
		To earn 3 per cent				
10	$1.58	$2.14	$2.70	$3.27	$4.39	$5.52
20	0.79	1.07	1.35	1.63	2.19	2.76
30	0.53	0.71	0.90	1.09	1.46	1.84
40	0.39	0.54	0.68	0.82	1.10	1.38
		To earn 4 per cent				
10	2.44	3.21	3.97	4.75	6.26	7.79
20	1.22	1.60	1.99	2.37	3.13	3.89
30	0.81	1.07	1.32	1.58	2.09	2.60
40	0.61	0.80	0.99	1.18	1.57	1.95
		To earn 5 per cent				
10	3.77	4.82	5.86	6.91	9.00	11.10
20	1.89	2.41	2.93	3.45	4.50	5.55
30	1.26	1.61	1.96	2.30	3.00	3.70
40	0.94	1.20	1.46	1.73	2.25	2.75
		To earn 6 per cent				
10	5.80	7.26	8.71	10.16	13.08	15.97
20	2.90	3.63	4.35	5.08	6.54	7.98
30	1.93	2.42	2.90	3.39	4.36	5.32
40	1.45	1.81	2.18	2.54	3.27	3.99

NATURAL CONVERSION OF ASPEN TO CONIFERS

Considering the large areas on which aspen is now unmarketable and the probable oversupply for some years to come, the conversion of aspen to less abundant and more valuable species requires thoro consideration. The proportion of the aspen-birch lands that have appreciable numbers of white or Norway pine, white or black spruce, balsam fir, or northern white cedar with or under the aspen, in the northern Lake States region, is estimated at between 10 and 20 per cent. Certain areas that have had special protection from fire, such as the National Forests in Minnesota (Fig. 6), the State Forest in Vilas County, Wisconsin (Fig. 7), and an area near Drummond, Wisconsin, where cut-over pine lands have been protected from fire by the company owning them, have considerable numbers of conifers on 30 or 40 per cent of the aspen type. More commonly, however, wide areas of the aspen type have only a negligible number of conifers in mixture.

Of the conifers that make up the 15 per cent of the aspen type being converted naturally, balsam fir is the most aggressive. Considering as a whole the area where aspen was mixed with conifers in St. Louis County, Minnesota, Hansen (1923) found the percentage of representation of the different species to be, for balsam fir 54, for Norway pine 20, for spruce 14, and for white pine 12. These proportions vary in different parts of the region and depend to a considerable extent on the composition of the old growth that was cut. The mixtures

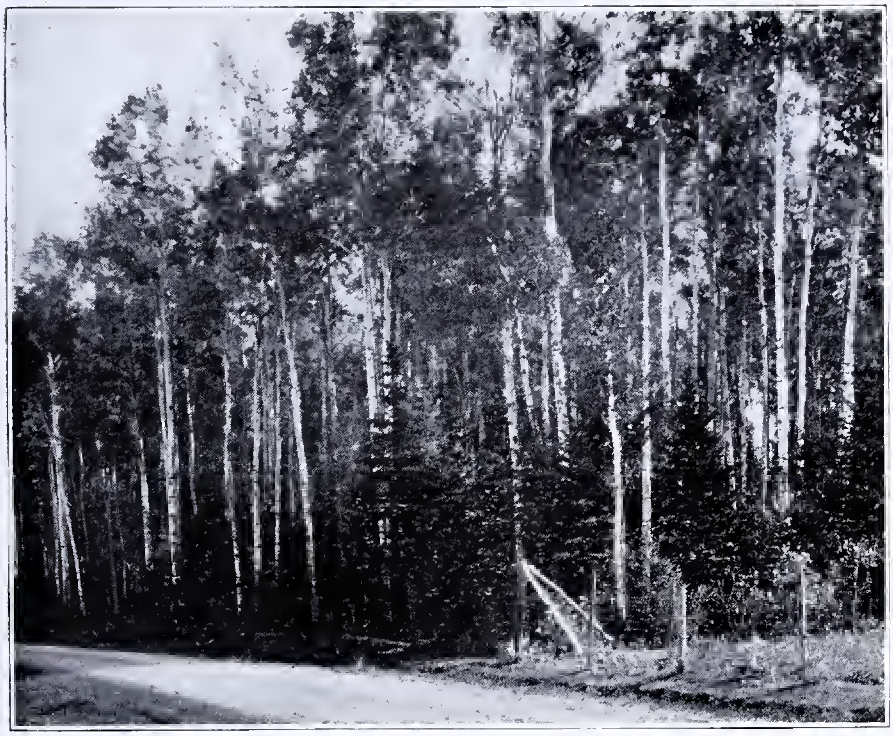

Fig. 6. Natural Conversion of Aspen-Birch to Balsam Fir
St. Louis County, Minnesota

of Norway pine and aspen are usually found on sandy, gravelly soils where the old stand contained considerable proportions of Norway pine. Black spruce occurs with the aspen in the margins of black spruce swamps, particularly in northeastern Minnesota. White pine is the

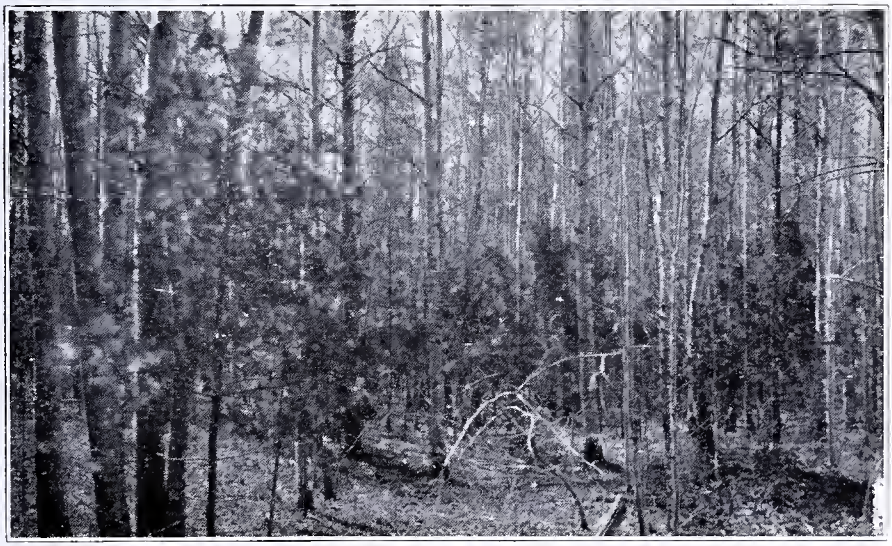

Fig. 7. Natural Conversion of Aspen to Norway and White Pine
Oneida County, Wisconsin

predominating associate of aspen in the belt through north central Wisconsin and Minnesota where heavy white pine stands were logged. Similarly, white spruce with the aspen is found most commonly in northern Minnesota in areas where white spruce predominated in the original forest (Kenety, 1917).

On the whole, if only 15 per cent of the area of the aspen type is being converted naturally to conifers and of that 15 per cent, balsam fir, the least valuable, contributes the largest part, natural conversion does not offer a prompt solution of the problem of the aspen lands. Is the proportion of the aspen type that contains a mixture of conifers increasing? If so, how fast, and what are the prospects that it will increase more rapidly in the future? Several elements affect the process and will be considered separately.

Advance Growth in Original Coniferous Stands

Large areas of the stands of old-growth white and Norway pine and white spruce and balsam fir were sufficiently open or irregular that seedlings of those species had become established in considerable numbers before the timber was cut. There were usually enough to form a new stand. Seedlings of balsam fir, white spruce, and white pine, most of which were established before the cutting, were found by Robbins (1928) at the rate of 456 to 3,074 to the acre on an area cut over 3 to 5 years previously at the eastern end of the Upper Peninsula of Michigan. Counts of 1,300 to 21,500 white pine seedlings to the acre under stands of old-growth white pine have been cited. An examination of the cut-over areas on the Chippewa National Forest, shortly after the cutting, showed the existence of a large amount of advance growth (Zon, 1912). It is almost always evident in the remaining stands of old-growth pine and spruce that have not been recently burned. The age of many of the larger conifers associated with the aspen indicated that they were survivors of the advance growth, which started before the original stand was cut and escaped subsequent fires. Except for the fires, most of the aspen-paper birch area would be covered with second-growth pine, spruce, and balsam fir from the advance growth in the old stands.

Source and Supply of Coniferous Seed

The old stands of pine or spruce bore seed abundantly, at least every few years. After the seed years, a good supply of seed was on the ground at the time of logging, especially on areas of white pine, because part of the seed does not germinate until the second season. The early logging left almost all the balsam fir and the pines and spruces that were too small to be merchantable but still large enough to bear seed.

These trees scattered seed after logging, altho that source of seed has gradually diminished as the trees have been wind-thrown or destroyed by fire. They also provided some shade on the cut-over areas. On the whole, therefore, the few years immediately after logging and before the aspen cover was complete were favorable for the seeding and establishment of the conifers. The age of the conifers in the present aspen stands shows that a considerable part of the pine and spruce was established at the time of or just after the old cutting.

Seed Trees

Some medium-sized and most of the defective trees of all sizes of pine and spruce were left at the time of logging and survived many years. They have served as seed trees, altho they were not left for that purpose. They have scattered considerable quantities of seed periodically in seed years. Altho most of the seed is eaten by rodents or birds, an occasional seedling starts under the aspen and promotes the process of natural conversion.

White and Norway pine and the spruces do not begin to bear seed in any quantity until they are 5 or 6 inches in diameter and 30 or 40 years old. The trees must be considerably larger before they are thoroly effective as seed trees. A moderately large seed tree of white pine produces from 12,000 to 25,000 seeds every 3 or 4 years (Fig. 8). A Norway pine seed tree produces 25,000 to 50,000 seeds every 6 or 7 years. The winged seeds are disseminated in considerable numbers for 300 to 500 feet from the parent tree. Notwithstanding these considerable quantities of seed, the remaining seed trees are not wholly effective, for there are rarely as many as 1,000 coniferous seedlings to the acre in the aspen stands near seed trees that have been producing seed for many years.

Few seed trees are left on the aspen lands and they are usually isoalted or in widely scattered groups. Considerable numbers of white and Norway pine remain on the Chippewa National Forest, where they were reserved, and on other state and national forests where they have been protected. Elsewhere, the small number of seed trees is one of the principal reasons for the unsatisfactory progress of natural conversion.

The relation between the number of established coniferous seedlings in aspen stands and the number or distance or direction of the parent seed trees is not definite. It has doubtless been obscured by the occurrence of fires and other causes of loss. On one area that had 10 white pine seed trees within 300 feet and at an average distance of 130 feet from the plot, only 200 seedlings to the acre were found. Good reproduction of white pine from seed trees was found on plots

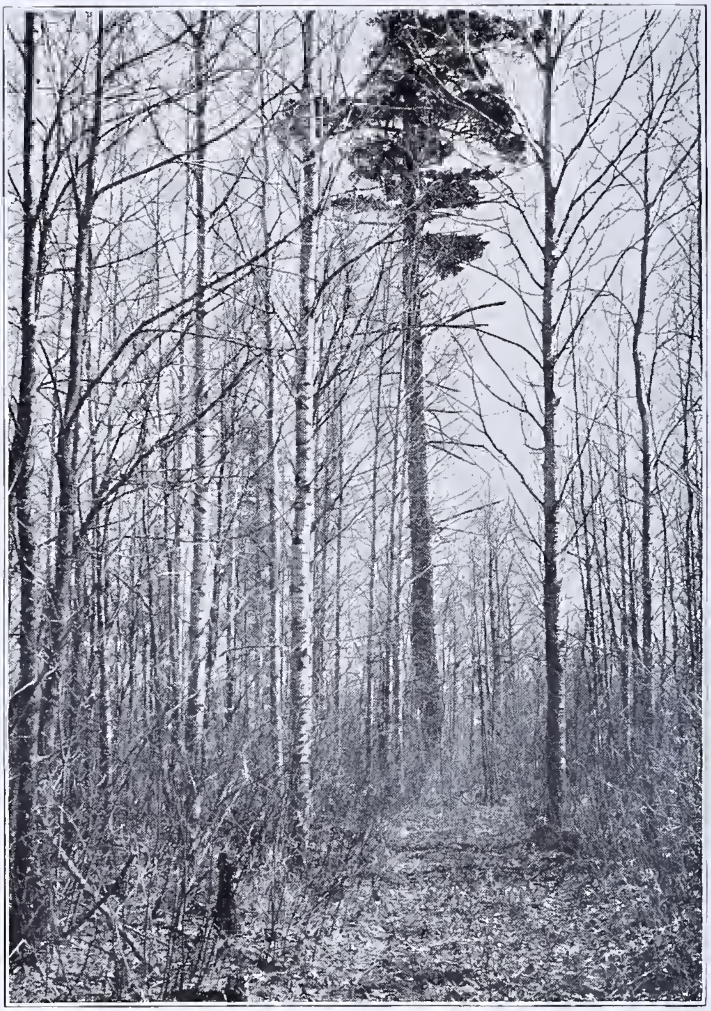

Fig. 8. Aspen Stand with Large White Pine Seed Tree
Chippewa National Forest, Minnesota

in Cheboygan County, Michigan, only where there were more than 5 seed trees to the acre; the Norway pine reproduction was poor, even with as many as 14 seed trees to the acre (Cashen, 1923). A careful count of the seedlings on permanent sample plots in a 40-year stand of aspen on the Chippewa National Forest showed that 3 good white pine seed trees on 2 acres had produced only 200 seedlings to the acre in 9 years and were therefore only partially effective in reseeding. On another plot with 53 seed trees within 200 feet, or 10 to the acre, 748 seedlings had started in the 9 years. On a third plot, 8 seed trees to the acre, chiefly to the northwest and southwest, whence the prevailing winds blow, produced 1,300 seedlings to the acre. The conclusion is suggested that at least 4 good seed trees to the acre, the equivalent of a spacing of about 104 feet, and probably 7 to 10 to the acre, spaced about

70 feet apart, are needed to provide adequate natural reproduction in the aspen type.

Except in occasional small areas, the seed trees remaining on the aspen lands are too few and too widely scattered to convert the millions of acres to coniferous species in any reasonable period of time. The poor character of many of the trees left after logging, resulting in small production of seed; the large number that have died since logging; and the periodic occurrence of seed years, which only occasionally synchronize with favorable moisture and other conditions, make the establishment of coniferous reproduction from seed trees slow, irregular, and generally unsatisfactory. These are not the only elements, however, that influence the process.

Effect of Rodents and Other Forms of Animal Life on Establishment of Conifers

The interacting influences of the many forms of animal life in the forest on the processes of forest regeneration and development are extremely complex. Certain obvious things about them are known, such as the damage caused during the periods when certain forms of animal life become overabundant in relation to their food supply. In some ways animal life in the forest may be beneficial. Birds and squirrels and probably other animals carry and distribute tree seed. Some seeds that they hide and fail to find germinate and thus help in the dissemination of those species. Unquestionably, the lower forms of animal life, like the insects, protozoa, and bacteria, are sometimes extremely important in controlling outbreaks of higher forms that are doing great damage to the forest, and in maintaining and promoting desirable physical and chemical qualities in the forest floor and soil.

For the most part, however, available information about the effect of animal life in the conversion of aspen bears upon its influence in hampering the establishment of the conifers. The lack of abundant or even satisfactory reproduction of pine and spruce in the aspen stands is certainly due in part to the scarcity of seed left to germinate. Red squirrels, ground squirrels, chipmunks, mice, and certain finches, such as the grosbeak and the crossbill, regularly eat conifer seeds, particularly those of the pines. Instances are cited by Pulling (1924) of poor and even of good seed years in which red squirrels cut all the cones on white pine seed trees days or weeks before maturity. The large proportion of Norway and white pine cones collected on the ground from caches or immediately after they are cut by squirrels offers additional evidence. In aspen stands where few seed trees are left, the rodents and birds undoubtedly get most of the seed in poor seed years and a large part of it even in heavy seed years.

Additional concrete evidence is provided by the seed spots of white pine and white spruce under 40-year aspen on the Chippewa National Forest. Part of the spots were protected by wire screens of one-quarter inch mesh for comparison with those not protected. The germination percentage for white pine at the end of the second season was increased as a result of screening from 2½ per cent to 8 per cent where the forest floor was left, and from 5 per cent to 22 per cent where it was removed. For white spruce the increase was from 9½ per cent to 15 per cent. There was evidence that some small rodent had burrowed under the buried edges of the wire and come up under the screens, so the protection was probably not complete. Even so, the considerable increase in seedlings may be attributed to the protection of the seed from rodents. At the Petawawa Experiment Station, in Ontario, similar protection of seed spots with wire screens gave an enormous "catch" of coniferous seedlings.

Hardly less important than the effect on seed supply is the direct damage done by various animals to established coniferous seedlings. Deer, when they become abundant, may browse the foliage of coniferous trees, as they have done in the aspen type in Itasca State Park, Minnesota. Squirrels and birds occasionally nip off the terminal buds (Hosley, 1928). Porcupines gnaw the bark from the upper parts of the trees and sometimes girdle them, so the tops are killed. These are minor forms of damage, however, and have not been serious in the northern Lake States. Grazing sheep, goats, cattle, or horses, especially if they are confined in a limited area, are almost certain to damage and kill a part or all of the coniferous growth within their reach. This damage is localized near farms and will be serious only locally as long as a large part of the aspen type remains unsettled.

The most serious animal damage that has occurred recently was caused by snowshoe rabbits when they increased to enormous numbers in 1925 and 1926 and at intervals of 6 or 7 years prior to that time. The damage by the rabbits is done chiefly in late winter or spring when the snow crusts over and they are forced to feed on the tops of the coniferous trees between 1 and 4 feet high that project above the snow. The best evidence of damage by rabbits may be found in plantations of pines made at various places in northern Minnesota in the aspen-birch type. Near Orr, in Itasca Park, and on the state and national forests in northeastern Minnesota, hundreds of acres of plantations were so nearly destroyed that only an occasional stub of a planted tree with its foliage partly or completely eaten off could be found (Fig. 9). Unquestionably, the natural reproduction of pine and spruce in these localities suffered as much. The damage to white spruce, white and Norway pine, black spruce, and balsam fir at Cloquet, Minnesota, has

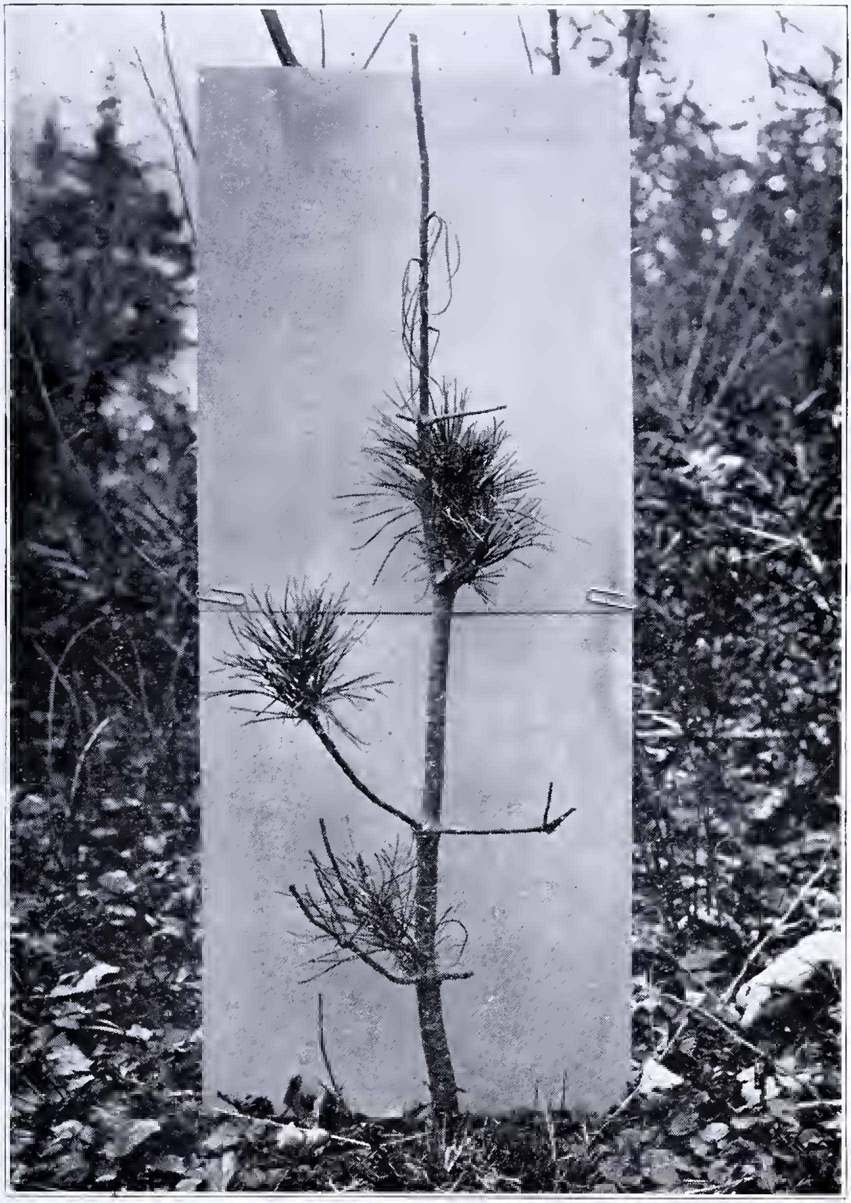

Fig. 9. White Pine Damaged by Snow-Shoe Rabbits

been reported by Corson and Cheyney (1928). Their conclusions coincide with those from a more extensive study by the Lake States Forest Experiment Station, in which all the species, with the possible exception of balsam fir, which is distinctly less susceptible than the others, were found subject to serious damage by rabbits. The rabbit damage in Wisconsin and Michigan was less severe, altho it was noted in 20 out of 30 of the white pine plantations in the aspen type. Sometimes 90 per cent of the trees were injured, altho more commonly less than half were damaged. Many of the damaged trees would, apparently, recover.

The rabbit damage was heavier near swamps and in brushy thickets where the rabbits, concealed from their enemies, abound. The 6- or 7-year intervals between the years of abundance, when the rabbits do the greatest damage, unfortunately are not long enough for the conifers under the aspen to grow above their reach. If these peaks in the rabbit population continue to occur at 7-year intervals, they offer a serious obstacle to the conversion of aspen to conifers.

Effect of Fire in Preventing Establishment of Conifers

Forest fires are chiefly responsible for the scarcity of conifers and for their absence over large areas of the aspen lands. One slash fire like those that covered the pine areas just after cutting destroyed most of the advance growth under the old forest. Repeated fires since have destroyed the few trees that escaped the first fires or that have subsequently germinated. Fires have also destroyed the seed trees that were left, and it is only because of their thick, resistant bark that the larger white and Norway pine seed trees have survived. Howe (1912) gives striking examples of similar conditions in Nova Scotia, where fires destroyed the coniferous growth and prevented or retarded its re-establishment on burned areas occupied by aspen and paper birch. As repeated fires increase the density of the aspen cover by replacing the older stand with a denser young stand, they probably in this way still further hamper the introduction of conifers. Effective fire protection is a first essential for the conversion of the aspen type.

The Aspen Forest Floor

The accumulation of leaf litter and humus in aspen stands unquestionably affects the establishment of the conifers in several, and probably conflicting, ways. The forest floor varies from a negligible thickness just after a fire when the new crop of aspen suckers starts, to 3 or 4 inches in dense stands of 50 years. It is usually about one inch thick. Several determinations on samples of one square foot from stands 20 to 55 years old have shown that the oven-dry weight of the forest floor amounts to from 4 to 30 tons to the acre. Obviously this layer of organic matter, which is highly absorptive of moisture and comparatively rich in plant nutrients, must have important influences directly and indirectly on the establishment of the conifers.

One immediate effect of the forest floor is detrimental. The germination percentage after the second season, in seed spots of white pine and white spruce, was increased by the removal of the forest floor in the following average percentages on 4 plots: (1) 2.5 to 5, (2) 8 to 22, (3) 1 to 9.5, and (4) 0 to 15. Seed sown in a potted soil sample of the forest floor from the same area gave only 3 per cent germination of white pine and 10 per cent of Norway pine from seed that gave 14 and 66 per cent, respectively, in adjacent pots of soil from pine stands. Experimental plots in Ontario, where seed was sown on burned soil, on hacked soil, and on undisturbed soil, indicate rather conclusively the advantage of hacking the soil. Poor results were obtained on the undisturbed forest floor and by complete destruction of the forest floor. Hacking was more favorable than burning. The unfavorable effect of the forest floor may be due to several causes, of which two well established ones may be mentioned: (1) The excessive drying of the forest floor during periods of drouth when its moisture content may readily be reduced to a point at which newly germinated seedlings whose roots have not penetrated the mineral soil would succumb. (2) Aspen leaves, after they fall and are compacted by the snow during the winter, form a mat that may easily smother small seedlings.

Effect of Shading and Competition with Other Vegetation

Many coniferous seedlings under stands of aspen die, from the time of their establishment for several years. This may be due to several causes, which are not distinguishable but would certainly include shading and root competition of the aspen and other tree species and of the shrubs and herbaceous vegetation. Fungi and micro-organisms take their toll. Excessively high temperatures in open stands and periods of extreme drouth also cause losses. The combined effect of these causes often results in the death of more than half the coniferous seedlings that germinate in any year. Definite evidence on this point is available from the three annual counts of reproduction quadrats in the 40-year aspen stand with white pine seed trees on the Chippewa National Forest. Many new seedlings were found and marked in 1925. One year later the losses had been 27 per cent in the plot with one third of the overhead cover removed, 66 per cent in the plot with one half the cover removed, 38 per cent in the uncut plot, and 17 per cent in the clean cut plot. The percentages dying of the total number of seedlings established from 1918 to 1924 on the corresponding plots amounted to 17, 26, 25, and 25, respectively. These heavy losses are not more than balanced by new germination after good seed years.

If the records of the 40 white pine underplantings from 5 to 15 years old in aspen stands are classified according to the amount of tree cover, the average losses were 50 per cent in stands with 5 to 24 per cent cover, 37 per cent in those with 25 to 60 per cent cover, and 54 per cent in those with 65 to 80 per cent cover. These figures suggest (1) that the lack of shade in the open stands of aspen results in losses from heat or frost; and (2) that too dense cover causes equally heavy losses, owing either to lack of light or to root competition of the overhead stand for moisture.

The possible damage to pine seedlings by excessive heat at the surface of the soil in the open has been demonstrated. The experiments of Toumey and Neethling (1924) showed that surface soil temperatures of 122 degrees to 139 degrees F. or more were often fatal to young seedlings of white and Norway pine. They obtained many readings above 122 degrees and a maximum of 152 degrees in southern New Hampshire. Gleason (1917) recorded the following temperatures in an aspen area in Cheboygan County, Michigan, during the hot weather in July, 1917, when the air temperature went above 100 degrees F.

Location of thermometer	In open, degrees F.	In aspen thicket, degrees F.
Bare surface soil	140	...
Ground debris	125	107
Shade of brake fern and herbs	112	109
Two inches in the soil	101	85
Four feet high, shaded	...	106½
Four feet high, in sun	...	108

Evidently the heat at the surface of the soil in openings in the aspen forest may injure or kill small pine seedlings when the maximum air temperatures in the shade exceed 90° F. Conversely, some aspen cover favors the pines by preventing such losses.

Further evidence of the effect of aspen cover is found in the aspen stands with a natural understory of conifers. All the aspen stands that had more than 200 conifers to the acre of any species were understocked on the average from 30 to 40 per cent by basal area. The detrimental effect of aspen-birch cover on the establishment of conifers is noted by Howe (1912) in Nova Scotia. On an area run over by a ground fire after being cut 10 years previously, where 2 white pine, 6 red spruce, and 2 balsam fir seed trees remained to the acre, a square rod yielded 27 fir seedlings, 19 white pine, and 5 red spruce. Adjacent birch-poplar (aspen) thickets averaged only 2 white pine seedlings to the square rod. On the other hand, in comparison with other types of cover, the Michigan Land Economic Survey, in Ogemaw County, concluded that aspen favors pine reproduction. They report, "Almost all of the white and Norway pine seedlings found in the county were under stands of poplar" (aspen).

Experiments by the Dominion Forest Service in Ontario with natural seeding of white pine in stands of birch and aspen have led to the preliminary conclusion that there is no difficulty in obtaining reproduction but that seedlings do not survive more than one or two years. Experimental cuttings have shown that open stands after cutting have better coniferous reproduction than those left uncut. Direct seeding also gave best results under the more open stands. In those having 30 to 40 square feet basal area reserved, only 9 to 15 per cent of the seedlings died; in those with 50 to 60 square feet basal area, 19 to 26 per cent died.

The relation of the amount of coniferous reproduction to the density of the brush is not well defined, altho the tendency is for the number of seedlings to decrease as the brush density increases. Most of the areas with an appreciable number of small conifers had brush densities of not more than 0.3. This general statement applies to white pine, Norway pine, balsam fir, white spruce, and black spruce. The notable exception was one plot having 1,350 white pines to the acre with a brush density of 0.6. The smaller number of conifers in brushy areas may be due, not directly to the brush but to the greater damage by rabbits, which abound in such areas. On the other hand, the root systems of hazel and large-leafed aster in Itasca Park occupy almost completely the upper 6 inches of soil, from which Lee (1924) concludes "that the failure of reproduction of the pines is largely due to the presence of this thicket undergrowth. This fact is well indicated by the presence of many one year old pine seedlings and the entire absence of seedlings of any greater age. During the spring, which is usually rather dry, the soil moisture in the surface layer would easily be exhausted by this heavy-foilaged undergrowth. Then the dense shade, combined with a critical desiccation would be sufficient to kill the feeble pine seedlings."

The general conclusion may be drawn that except for the first few years after fire or cutting, the conifers do not increase in number as the aspen stands grow older. The number may, however, remain nearly constant or fluctuate from year to year as the older seedlings that die are replaced by new ones.

Growth of Conifers in Aspen Stands

The characteristic feature of pine, spruce, and other conifers associated with aspen is their small size in comparison with the aspen. All the conifers grow more slowly in height, diameter, and volume, at least during the first 20 years, than does aspen. This is true even when the conifers are growing in the open and are not suppressed by a larger stand of aspen. Jack pine is the one exception. It grows nearly as rapidly as aspen from the beginning and unless it keeps pace with the aspen in height growth it soon succumbs. Consequently, where jack pine is found in mixture with aspen it is usually in group-wise mixtures in which the jack pine is as large as the aspen. This mixture occurs commonly only in northeastern Minnesota and will not be considered further because jack pine is not likely to be useful in the conversion of aspen to conifers.

The other conifers—white and Norway pine, white and black spruce, balsam fir, and northern white cedar—are sufficiently important to require detailed consideration of their growth in height, diameter, and volume in comparison with that of aspen.

Height Growth

The heights attained by the different conifers at successive ages are shown in Table VIII for the two classes of trees that, for lack of specific terms, have been called "crowded" and "not crowded." The "crowded" trees include those that grew in comparatively dense stands or in groups of larger aspen and consequently were retarded in growth by shade and by root competition. The "not crowded" trees are those that grew in understocked aspen stands or in small openings of denser stands. They had some light from above and suffered less from root competition. The first significant point indicated by the figures is that all conifers grow slowly in height during the first 20 years. This is partly an inherent characteristic, particularly in balsam fir and the spruces, and partly the result of suppression by the aspen, which overtops them. As a result, at 15 years of age, when the aspen averages 22 feet high, the white and Norway pines are only from 3 to 10 feet high, the spruces and balsam fir from 2 to 6 feet, and northern white cedar one foot.

TABLE VIII

HEIGHT GROWTH OF ASPEN AND ASSOCIATED CONIFERS

Age	Aspen		White pine		White spruce		Norway pine		Balsam fir	
	Site index		Not crowded	Crowded	Not crowded	Crowded	Not crowded	Crowded	Not crowded	Crowded
	50	60								
years	Average total height, feet									
10	14	15	4	2	3	2	5	3	4	1
20	26	29	13	6	11	5	17	9	11	4
30	36	40	28	15	25	12	31	20	25	10
40	44	49	39	25	37	22	41	28	43	22
50	52	58	46	32	46	30	49	34	54	33
60	58	65	51	36	52	35	54	38	60	42
Basis, number of trees	..	..	103		33		37		158	

The average number of years required for the four principal conifers to attain a height of 4½ feet in "crowded" and "not crowded" conditions was as follows:

Species	Not crowded, years	Crowded, years
White pine	10	18
Norway pine	11	15
Balsam fir	16	24
White spruce	16	22

This information is often useful in connection with determinations of total age of larger trees. The appropriate figure from the table is added to the number of rings at breast height to obtain the total age.

From 20 years of age to 50 or 60 years, the pines, white spruce, and especially balsam fir increase more rapidly in height but, owing to their slow start, the two most desirable species, white pine and white spruce, remain 15 to 25 feet shorter than the aspen up to 50 or 60 years. Only an occasional pine or spruce is as tall as the aspen at these ages, usually because they had passed their early period of slow growth in the original stand before the aspen started.

These comparisons apply to white pine, white spruce, and balsam fir, which occupy approximately the same average site as aspen. Norway pine, however, attains the heights shown in Table VIII on poorer sites represented by site index 55 for aspen. Norway pines that are not crowded, therefore, may be expected more nearly to overtake the aspen on these sites at 50 years. The other conifers may also maintain their growth as the growth of the aspen declines on the poorer sites, altho available data do not afford proof of the possibility. The suggestion is probably justified, however, that conversion of aspen to conifers is more likely to have a successful outcome on the poorer sites for aspen.

After the aspens are 60 or 70 years old they begin to die out, openings in the stand are formed, and the conifers take advantage of the increased space and continue their height growth until they are more than 100 years old.

The height growth of the crowded conifers is strongly influenced by the amount of space they have. At 60 years they average about 17 feet shorter than trees that have not been crowded. Badly suppressed trees may be considerably shorter at the same ages than are the average "crowded" trees. In extreme cases, white pine or white spruce trees were only 10 to 12 feet high at 40 years. The crowded trees, in general, can not be expected to overtake the aspen.

At early ages the pines are taller than spruce or balsam fir, which are noted for their slow growth in height at the beginning. Later, white spruce and especially balsam fir rapidly improve their original stunted height growth to such an extent that the fir is the tallest of the 4 species from 40 or 50 to 60 years.

The growth in height of white pine, measured on 27 plantations 5 to 15 years old, may illustrate the effect of the density of the aspen cover on the height growth of that species. Where the aspen-birch cover occupied less than 40 per cent of the area, the average annual height growth was 0.34 foot; under 60 to 80 per cent cover it was 0.21 foot. The average annual height growth of planted white pines under or close to the crowns of larger aspens or birches was 0.28 foot, as compared with 0.36 foot for those not directly suppressed.

The most significant fact in the comparative height growth of conifers and aspen is that the conifers, with the exception of the "not crowded" trees on the poorer sites, remain below the aspen and do not overtake it until the aspen stand begins to deteriorate.

Diameter Growth

The growth of conifers is more variable in diameter than in height because it is more affected by the density of the stand and the degree of suppression. Table IX gives the average diameters of the four important kinds of conifers at different ages for "crowded" and for "not crowded" trees. Northern white cedar grows more slowly than these four. Up to 30 years, Norway pine shows the most rapid diameter growth because it is found in aspen stands only where it has had an opportunity to grow in openings. From 40 to 50 years, as the openings close and the competition between the larger trees becomes more intense, its rate of growth becomes less than that of the other conifers, showing its greater susceptibility to crowding. White pine and white spruce increase in diameter for the first 40 years at about the same rate. Thereafter the white pines average larger, probably because only those survive that have relatively ample growing space, while more of the spruces live and grow slowly as suppressed trees. Both species have an average diameter of 6 or 7 inches in 60 years—some trees 11 or 12 inches. An average diameter of 7 inches in a stand of pine or spruce represents a merchantable stand wherever there are enough trees to the acre to provide a merchantable volume for cutting. The diameter growth, therefore, indicates that a merchantable understory of white pine or white spruce may be produced in aspen stands that are not too dense in 60 or 70 years. As the aspen begins to die at 70 or 80 years, giving the conifers more space and light, there is good reason to believe that the pine and spruce would maintain and possibly increase their diameter growth for another 20 or 30 years.

TABLE IX
DIAMETER GROWTH OF CONIFERS ASSOCIATED WITH ASPEN

Age	White pine		White spruce		Balsam fir		Norway pine	
	Not crowded	Crowded	Not crowded	Crowded	Not crowded	Crowded	Not crowded	Crowded
years	Average diameter breast high, inches							
20	1	..	..	..	1	..	2	1
30	4	2	4	2	3	1	5	3
40	7	4	7	3	6	3	7	5
50	9	5	8	4	8	4	9	6
60	11	6	10	5	10	6	..	..
Basis, number of trees	124		40		158		40	

Volume Growth

The growth in volume of trees, as a composite of growth in height, diameter, and form, is for that reason more variable than the growth in either height or diameter and consequently average figures are less satisfactory. They have little significance except in connection with the number of trees per acre, which is also extremely variable. The volume, or yield per acre, which is the product of these two variables, gives the most useful practical information. The average volume per acre of conifers of all species increased with age from 230 cubic feet, or about 3 cords to the acre, at 30 years to 420 cubic feet, or 5 cords, at 50 years and 550 cubic feet, or 6 cords, at 60 years. Individual areas showed wide variations due to causes such as the origin and fire history of the stands, which had affected the number of trees to the acre.

Volume production is not determined primarily by the density of the aspen, except that the volume of the conifers is uniformly low in stands of aspen that are denser than the average for well stocked stands. No essential difference is found, however, between the stands from 0 to 30 per cent understocked and those that are more than 30 per cent understocked. Several stands that were from 0 to 30 per cent understocked had comparatively large volumes of conifers. For example, in one 60-year stand of aspen there were 1,100 cubic feet, or about 12 cords, of conifers to the acre, and in two 75-year stands there were, respectively, 1,220 cubic feet, or 14 cords, and 1,817 cubic feet, or 20 cords. The largest volume of balsam fir recorded on any one area was 18 cords in a 65-year old stand of aspen that was 33 per cent understocked. The best white spruce volume was 11 cords to the acre in a 60-year stand of well stocked aspen. Of white pine, 2,500 board feet to the acre was found in a 47-year stand of aspen 45 per cent understocked; and of Norway pine, 980 board feet in a 41-year stand of aspen 9 per cent understocked.

The figures for volume per acre, like those for diameter, indicate that it is possible to produce merchantable stands of spruce and pine in 60 to 75 years if they are started and grown under a cover of aspen, in addition to the yield of aspen from the same area.

As the stands grow older the aspen gradually disappears, and after 70 years its place is taken by the conifers. Thus the stands change in character, cease to be recognizable as aspen, and would be classified as pine or spruce. In this period the conifers increase rapidly in volume, particularly in merchantable board-foot volume.

The transition from aspen to white spruce is illustrated in Table X from data by Kenety (1917), who considered that the plots represent the white spruce type.

The rate of growth in diameter of white spruce in aspen stands (Table IX) indicates that at least the "not crowded" trees would attain diameters of 11 or 12 inches in 100 years. Kenety's data show that only 38 trees to the acre of this average size yielded 12 cords, with 13 cords additional of aspen that was still living.

TABLE X

ACRE PLOTS OF ASPEN-WHITE SPRUCE*

Age, yrs.	Trees per acre more than 4 in. in diam. breast high	Av. diam. breast high in.	Av. height, ft.	White spruce Yield		Balsam fir Yield		Aspen Yield		Total Yield	
				Cords	1,000 board feet	Cords	1,000 board feet	Cords	1,000 board feet	Cords	1,000 board feet
100	38	12.3	80	12	6	1	..	13	4	26	10
100	8	12.4	75	2½	..	12	1	13	4	27½	5
103	7	11.0	70	1	1	..	..	10	4	11	5
106	28†	15.7	87	15	7	14	..	8	4	37	11

* Data from Kenety, 1917.

† More than 9 inches.

Five cords to the acre in places where the timber is reasonably accessible is usually considered a merchantable stand of spruce. If this figure is assumed as the criterion of a merchantable stand, it is possible by the use of volume tables (Cloquet, 1926) to indicate roughly how many trees of different average diameter to the acre would be required to yield 5 cords. The figures are given below in tabular form.

White Spruce

Av. diameter breast high, in.	Volume per tree, cords	Trees per acre to make 5 cords
6	0.04	125
7	0.06	83
8	0.08	63
9	0.11	45
10	0.15	33
11	0.20	25
12	0.24	21

These numbers, ranging from 125 trees 6 inches in diameter to 21 trees 12 inches in diameter to the acre and sometimes more, are found on small areas in natural stands.

With white pine it may be assumed that 5,000 board feet, mill tally, to the acre represents a merchantable stand. The number of trees of different average diameters required to yield 5,000 board feet to the acre is shown in the following tabulation.

The number of trees in this case, from 312 to 58, is larger than for white spruce but still well within those sometimes found in natural stands of aspen. An understory of numerous spruce or pine seedlings may easily pass unnoticed in a stand of aspen, whereas, by the time the conifers reach 50 years, the same number of trees would evidently form a good stand. In this way the future value of what appears to be a sparse reproduction of small conifers is often underestimated or entirely disregarded.

White Pine

Diameter breast high in.	Height ft.	Volume per tree (mill tally) bd. ft.	No. of trees to make 5,000 bd. ft. per acre
6	34	16	312
7	37	25	200
8	39	35	143
9	41	45	111
10	43	58	86
11	44	71	70
12	45	86	58

On the basis of diameter growth, number of trees, and volume per acre, it appears possible to grow a merchantable crop of white pine or white spruce in the aspen type, in from 60 to 100 years, either from natural reproduction or by planting a moderate number of trees to the acre.

Relation of Growth of Conifers to That of Aspen

The conifers under aspen are usually crowded. Their slow growth during the first 20 years, while the aspen is shooting up rapidly, is evident from a comparison of the figures given for the growth in height of conifers and of aspen. Altho conifers that are not too much crowded grow comparatively well even under the aspen cover, they continue to lag behind the aspen not only in height but also in diameter and hence in volume for the 50 to 70 years while the aspen is growing vigorously. Comparing them at 50 years on an average site, the aspen reached 58 feet in height while the white pine and white spruce reached an average of 40 feet. The difference in diameter and volume per tree is less marked. In volume per acre, however, owing to the smaller number of pine and spruce and to their small dimensions, the aspen had 3,220 cubic feet at 50 years, while white pine averaged only 310 and the other conifers only 420 cubic feet. Only after the aspen deteriorates from decay and old age, usually after 70 years, do the conifers overtake the aspen in dimensions and volume per acre. The figures in Table X for white spruce stands 100 years old are examples of the stage in the natural conversion of the aspen to white spruce at which the aspen has partly died out and the white spruce has just become the dominant tree.

The process of natural conversion is complicated by the different densities of aspen and by the several species and sites, all of which have their influence. As a result there is wide variation in the development of individual trees of pine, spruce, and balsam fir in the different areas studied and there is an even wider variation between the averages of the plots. These variations render generalizations unsatisfactory and unreliable. The one thing that stands out plainly is the slow growth of the conifers as compared with that of the aspen. Next is an evident tendency for conifers that grow in openings to develop more rapidly than those close to or under larger aspens. This is the reason that figures on growth of conifers were presented under two broad headings—"crowded" and "not crowded" trees. The same tendency was also indicated by the data from planted white pines discussed under "Height growth." From this evidence, the conclusion follows logically that the less dense, understocked aspen stands with openings between the trees are favorable for the growth of conifers. Furthermore, the conifers on sites poor for aspen are in a better position to maintain themselves and take the lead at an earlier age.

Development of Conifers and Final Outcome

If growth of the conifers started before that of the aspen, or if a supply of coniferous seed from adjacent stands or from seed trees was available, the conifers developed in sufficient numbers to form a merchantable stand in addition to the aspen in 60 or 70 years. The early stages in the process of seeding of white pine are illustrated by the figures from a permanent sample plot in a 40-year well stocked stand of aspen on the Chippewa National Forest, where there were 7 good white pine seed trees within 200 feet of the plot. All the white pine reproduction started after a light ground fire in 1918. Up to and including 1924, more than 80 white pine seedlings to the acre had become established. In 1925, 20 of these died and 160 new seedlings started, making 220 to the acre; in 1926, 80 died and 60 new ones started, making 200 to the acre; and in 1927, 20 died and no new seedlings were found, making 180 to the acre. Thus the balance fluctuates from year to year, with a gradual increase in the number of seedlings over several years. Fewer of the seedlings die as they grow older, so gradually the larger, more vigorous seedlings form an understory.

When the pine or spruce starts at the same time, the aspen takes the lead and forms an overwood for 60 to 80 years—sometimes longer if it is left uncut. On the poorer sites, where Norway pine and black spruce are more often associated with the aspen, it rarely maintains its lead for more than 50 or 60 years. On the better sites, where white pine and white spruce are the usual associates, the aspen may live and retain its lead for 75 to 90 years. The conifers, however, are all comparatively long-lived. Balsam fir regularly lives to 100 or 120 years, the spruces to 150, Norway pine to 200, and white pine to 250. They increase in diameter and volume up to 120 or 150 years. This ability of the conifers to outlive the aspens, together with their capacity to seed and grow under the aspen are the two characteristics that enable the conifers to start and grow, at first inconspicuously, and then gradually to occupy the space left as the aspens die and finally to replace the aspen so that the stand ceases to retain its character as aspen type and becomes predominantly pine or spruce and balsam.

The process of natural conversion of aspen to conifers, however slow, is nevertheless effective and will come to fruition without human intervention. Unfortunately, however, natural conversion is taking place in only 10 to 20 per cent of the area of aspen lands. Cutting and fires have done their work too well by destroying coniferous reproduction and seed trees on the other 80 to 90 per cent of the area. In most parts of the region there is not likely to be much increase in the area that will be converted naturally within any reasonable time. In what other ways may the process be extended and accelerated?

MAN'S ASSISTANCE IN THE CONVERSION PROCESS

The conversion of the aspen type requires human assistance to be promptly and widely effective (Fig. 10). There are several ways in which it may be applied—protection from fire, cuttings of various kinds, preparation of the ground for natural or artificial seeding, and planting.

Fire Protection

Protection from fire is a first essential for conversion. If the conifers are already established, a fire through the area will kill most or all of them and postpone the conversion for many years, until a new crop can start. Protection from fire, by preventing the destruction of the conifers and thus allowing them to mature, replace the aspen, and seed in additional areas, promotes the conversion process. If fires had been prevented in the past, there would be only a fraction of the present area of aspen, and that fraction would have a good representation of conifers in mixture. Effective fire protection in the future is essential for the natural or artificial extension of the conversion process.

Cuttings in Mature Aspen

Any cutting has several immediate effects in the aspen forest that directly or indirectly influence the conversion process. Cutting a part or all of the aspen creates openings in the canopy and allows more light to reach the smaller conifers and the ground beneath. The sun's heat causes higher temperatures at the surface and below the surface of the soil. As a result there is a more rapid decomposition of the forest floor. At the same time, the increased heat and easier circulation of air cause a higher rate of evaporation and drying out of the forest floor in periods of drouth. These results of cutting are not clearly distinguishable one from another, either directly or in their effect on the conifers. The intensity of the changes, however, depends on the degree of cutting, so they are greatest in clear cuttings and progressively less with lighter partial cuttings. Cutting of the aspen results within the next year in a regeneration of aspen suckers which, as has been shown, are extremely dense after a clear cutting and progressively less dense after partial cuttings until they are unimportant if less than a third of the aspen is removed. The change from the mature stand to the young growth of suckers mixed with brush and luxuriant herbaceous vegetation apparently results in less serious competition for the conifers, at least for a few years after the cutting.

Effect on Associated Conifers

The combined net effect of the changes brought about by cutting the aspen is favorable to the development of both seedlings and large trees of white pine, white spruce, and other conifers. Evidence in support of this statement is available from permanent sample plot records both on the Chippewa National Forest and at the Petawawa Forest Experiment Station, in Ontario. In Minnesota the 40-year well stocked aspen plots were cut over in May, 1926, with the results on the natural white pine reproduction indicated in Table XI.

TABLE XI
MORTALITY OF WHITE PINE SEEDLINGS

Degree of cutting	1926* seedlings in 1927†	1918-26* seedlings in 1927†	1918 26* seedlings in 1926† and 1927†
	per cent	per cent	per cent
Clean cut	0	5	5
50 per cent cut‡	11	5	42
30 per cent cut‡	29	9	24
Uncut	33	10	36

* Years of origin.
† Years of death.
‡ Percentages based on crown cover.

The Canadian experiments indicate conclusively that cutting favors coniferous reproduction. In one series, in which 50 to 60 square feet of basal area of aspen and birch were left, between 19 and 26 per cent died. On plots having 30 to 40 square feet of basal area reserved only 9 to 15 per cent died. Plots in another series (Veness, 1923) in 40-year aspen-birch type, cut in 1920 to leave 1,715, 1,278, and 600 trees to the acre, were undersown with white pine and white spruce and the 1925 counts showed that 68, 95, and 38 per cent of the seedlings, respectively, had died. The growth of the conifers under the reserved stands was notably slow.[5]

[5] This information and that cited elsewhere from Canadian experiments without specific reference was furnished by letter through the courtesy of the Forest Service, Department of the Interior, Canada.

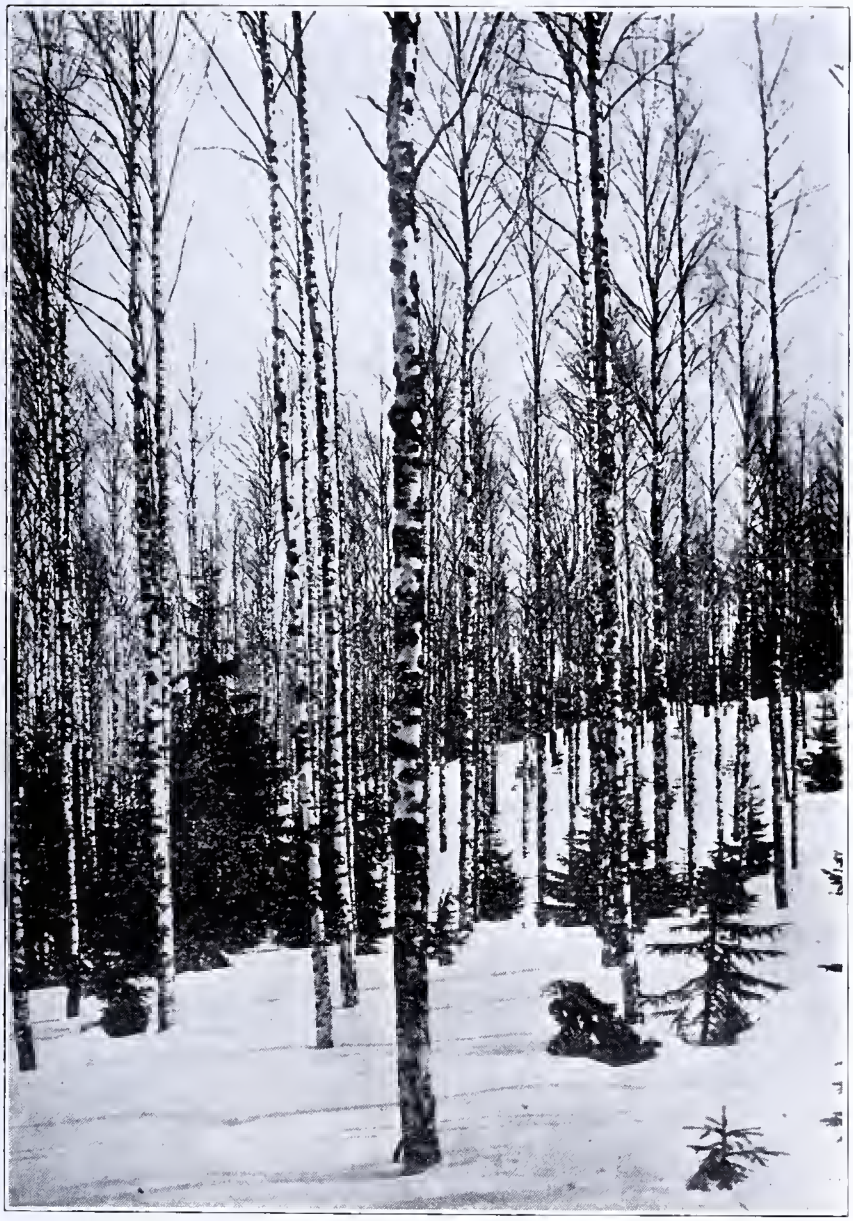

Fig. 10. Natural Conversion of Birch to Spruce Under Forest Management in Finland (Photo by courtesy of A. K. Cajander.)

In general, the heavier the cutting in the aspen the greater is the benefit in the survival and growth of white pine and other conifers. Clear cutting might on some areas and in some years result in damage to small seedlings by excessive heating of the surface soil or by sunscald. This statement is not substantiated by specific evidence, however, and such damage is probably prevented by the immediate regrowth of aspen suckers and other vegetation, which provide shade for the small seedlings. The larger conifers are least likely to be seriously damaged by the exposure. Ample evidence of the response of advance growth and larger conifers to release by the cutting of aspen and birch is available for white pine and spruce under somewhat similar conditions in the northeast, but not for the Lake States. It is reasonable to expect, however, that cutting of aspen in the Lake States would result similarly in stimulated growth of the conifers that had been suppressed

Losses resulting from logging aspen.—The conifers below merchantable size will almost inevitably suffer losses and damage when the larger aspens are cut. Swamping and skidding are likely to cover 10 to 25 per cent of the area and additional losses occur in connection with the felling. The heavier the cutting, the greater is the loss and damage. Clean cutting of a dense 40-year aspen stand in May resulted in the loss of 52 per cent of the white pine seedlings less than one foot high. Cuttings of 50 per cent or less in the same stand caused losses of less than 25 per cent of the white pine seedlings. On the whole, from 10 to 50 per cent of the conifers may be destroyed in logging. The damage and loss of the larger conifers that can easily be seen could be reduced, probably to less than 15 per cent, by care in felling and swamping, and in locating skidding trails.

The season in which the logging is done affects the conversion in two ways: (1) Winter logging on the snow eliminates most of the damage to and loss of seedlings less than one foot high that are covered by the snow. It may also increase the damage to small growth that projects above the snow and is easily broken in cold weather. (2) The season of logging affects the conifers indirectly by its influence on the number of aspen suckers that come up after cutting and compete with the conifers. Spring cutting produces the most suckers, summer cutting fewer, and fall cutting the fewest, according to Baker (1923). This effect of season soon disappears, however, because the number of suckers and their competition become equalized within 10 years after the cutting.

Release Cuttings

Any cutting made in the aspen before it is mature to release the smaller conifers in the understory from suppression by the aspen are included under this heading. Release cuttings presumably will increase both the survival and the growth of the conifers and thus enable them to reach merchantable size in a shorter time. As experience in the Lake States is again lacking, it is necessary to turn to the suggestive experience in the northeast, where white pine has been released from the competition of gray birch and red maple. Release cuttings may be carried out in several ways. One is to cut the aspens while they are still small and repeat the operation as often as may be necessary to save the pines and maintain their growth. By this method, the first release would be made when the aspen is only 3 or 4 years old. The cutting can be done cheaply with a machete, with which the stems are not completely severed. They are then bent over so that the roots are less likely to send up new sprouts. This operation should be carried out, preferably, in a season when the leaves are off, so that the smaller conifers may not be overlooked. The aspens should be cut that are close to the conifers and are already crowding or are likely soon to suppress them. Frequently the conifers occur in groups, and the release of a group as a unit is desirable. Altho no immediate return is obtained from such cuttings, they can be made more cheaply while the aspens are small than at a later time. On the other hand, a second release cutting may often be necessary within 10 or 15 years after the first (Cline and Lockard, 1925).

The second possibility is to postpone the release cutting to the latest time when a sufficient proportion of the white pine or other conifers may be expected to recover and benefit from the release—in New England, when white pine is 12 to 15 feet high and 10 to 25 years old, according to Spaeth (1922). It might sometimes be possible to obtain a money return from the small cordwood produced in the cutting, but this is unlikely at the present time in the Lake States. The chief advantage consists in avoiding a second release cutting after some years, which becomes unnecessary because the conifers are sufficiently tall that they will not be overtaken by the new crop of aspen suckers. Judging from the comparative height growth of aspen and the different species of conifers in the Lake States, the age at which to cut the aspen to accomplish this object would be between 15 and 25 years, or when the conifers are from 3 to 15 feet high.

Release cuttings may require from 1 hour to 2 days time for a man to the acre, depending on the number and size of the trees to be cut. The costs are ordinarily from $2.00 to $5.00 an acre (Fisher, 1918). Weeding of inferior hardwood for the benefit of pine gives the most productive results for the money expended of any intensive forestry work that may be carried on in New England, according to Hawkins (1924). He says that $2.00 to $7.00 an acre has been invested over large areas by a box company; in special cases $15 an acre has been spent to good advantage. Where conifers are established or planted, release cuttings must be considered as an aid or sometimes even a necessity in converting an aspen stand to conifers.

Disturbing the Forest Floor

That the aspen forest floor reduces the amount of germination of white pine, white spruce, and probably also of other conifers, whether naturally or artificially sown, has been indicated. Conversely, the removal of the floor in seed spots and the hacking or stirring up of the leaf litter by dragging brush increase the amount of germination. Hacking the forest floor gave higher germination than burning, in experiments by the Canadian Forest Service. Ordinarily, even if burning were effective in increasing germination, it would be inadvisable for several reasons.

The actual removal of the forest floor over considerable areas is not necessary and is undesirable because it would be costly and would deprive the soil of a valuable moisture regulator and fertilizer. The object is rather to stir up the forest floor in enough places that sufficient seeds to form a stand may find favorable germinating beds. Logging accomplishes this on a certain proportion of any area logged. In aspen stands that were to be sown before logging, dragging the tops of trees back and forth across an area, either as they were felled or with the smaller twigs trimmed off, would probably promote germination. Similar treatment in the autumn of a seed year should favor the natural reproduction of conifers. The benefit of such measures in relation to their cost has not been determined. Their possible value should, however, be considered in connection with any plan for conversion by natural seeding or broadcast sowing.

Sowing Seed

Direct sowing of the seed of conifers on the planting site has usually failed in the aspen type as elsewhere in the Lake States. Broadcast sowing has hardly a record of success, altho the preparation of the ground by hacking or dragging brush might be an aid in occasional favorable years.

Seed spot sowing has in some instances given satisfactory results. In an analysis of direct seeding methods for converting aspen and paper birch land to spruce and pine, Robertson (1926) gives averages for 17 experimental plots in Ontario. After 4 years, there were 340 seedlings per acre under dense shade, and 5,000 per acre under light shade. From intensive investigations in New Brunswick he concludes that the seed spot is the most economical and reliable of the direct seeding methods. It is not satisfactory, however, with white pine, because the comparatively large seeds are usually eaten by rodents. White spruce, on the other hand, was successfully spotted on recent burns under moderate shade and on north slopes. The seed-spot method may be recommended for use in the aspen-birch type on rocky shallow-soiled areas where planting would be difficult and costly. The costs in Canadian seed-spot sowing have usually been between $4.00 and $5.00 an acre. A slight additional cost would be necessary to thin out spots that had more than one tree at the time of the first release cutting. Experimental sowings of Norway and white pine in cleared spots one foot square, were not successful at Cloquet, Minnesota, on areas of young aspen mixed in the thick brush, where the hardwood leaves smothered the young seedlings (Kenety, 1917).

Seed-spot sowing of 10 seeds each of white pine and white spruce under 40-year aspen after different degrees of cutting on the Chippewa National Forest gave results in the second spring after the seed was sown as shown in Table XII. The experiment indicates that the removal or disturbance of the forest floor is essential for the germination of white spruce and only a little less necessary for white pine. Protection from rodents increases the success with both species. Protection by screening is impractical in an extensive reforestation operation; but without protection, the results, irrespective of the degree of cutting, are too poor for the method to be recommended.

TABLE XII
PERCENTAGE OF SEED SPOTS WITH ONE OR MORE LIVING SEEDLINGS

Kind of spot	Degree of cutting			
	Uncut	30 per cent cut	50 per cent cut	Clean cut
White Pine				
Natural forest floor	0	22	0	0
Natural forest floor screened	37	42	62	0
Forest floor removed	0	40	25	33
Forest floor removed and screened	75	83	75	50
White Spruce				
Natural forest floor	0	22	0	0
Natural forest floor screened	0	0	0	0
Forest floor removed	0	37	25	17
Forest floor removed and screened	25	100	100	50

Summing up available evidence on direct seeding, the method may have a use on rocky sites where planting is difficult and expensive. On such sites, seed-spot sowing of white spruce where there is a moderate amount of shade is suggested. Even under these circumstances the sowing should be on an experimental scale before a large operation is undertaken.

Planting in the Aspen Type

Some planting has been done under aspen in the Lake States. Records are available of 70 plantations from 5 to 10 years old of which 40 are white pine, 19 Norway pine, 6 Norway spruce, 3 jack pine, and 2 Scotch pine. The examples of jack pine and Scotch pine are insufficient as a basis for conclusions and neither species is recommended for planting on aspen sites. Norway spruce is believed to be less well adapted for planting in the aspen type in the northern Lake States than the native white spruce. Unfortunately, experience with white spruce plantings is limited; the older plantings were largely destroyed by rabbits in 1924 and 1925. Norway pine is not suited for underplanting and should be planted only on open or recently burned areas where the aspen is not too large and too dense. Its chief value is on the sandy, gravelly, dry sites where it grew originally and where the aspen stands are likely to be irregular and broken. The discussion of planting will be limited to white pine and white spruce, the two most suitable species for planting in the aspen type.

Favorable and Unfavorable Conditions for Planting

The shade of aspen and birch is favorable for white pine plantations when the density of the crown cover is between 0.3 and 0.7, and less favorable when it is below 0.3 or above 0.7. This applies to both survival and early height growth. The benefit of the moderate degree of cover in comparison with open sites is probably connected with the damage from excessive heat and frost that white pine seedlings suffer during the first year or two on exposed sites. The poorer results under aspen stands of more than 0.7 density are probably due to the competition of the larger aspen for light or root development. Hansen (1927) notes that the surviving planted white pines on a site with small aspen and thick brush were all in the open places or, conversely, chiefly those in the thickets died. This is further indicated by a comparison with planted pines immediately under or close to larger aspens that grew, on the average, 0.28 foot in height annually, while those in the openings grew 0.36 foot annually. A specific comparison may be made of two white pine plantations on the Alpena State Forest, in Michigan, similar in all respects except that one was planted under a 30-year stand of aspen with a density of 0.8 and the other where the aspen was only 5 to 10 feet high with a density of 0.5. In the first only 28 per cent survived and the trees averaged 0.6 foot high 4 years after planting. In the other, 64 per cent survived and the trees averaged 1.1 feet high. For natural reproduction, the more open stands of aspen and the areas immediately after cutting or fire offer more favorable sites for planting than the older, denser stands of aspen.

The slight effects of differences in soil on the survival of the planted pines are obscured by other factors. Growth tends to be less on the heavier loamy soils or on the low sandy soils near the water table, owing, probably, not so much to inherent qualities of the soil, as to the more serious damage by rabbits and the competition with other vegetation.

Snow-shoe rabbits are particularly abundant in the areas of young aspen stands and every seventh year, when they are particularly plentiful, they may almost completely destroy forest plantations, as they did in Minnesota in 1924 and 1925. The damage is more severe near the margins of swamps and less on dry sandy uplands (Corson and Cheyney, 1928). Rabbits are worse where the brush is thick than where it has been suppressed by a dense forest cover. If snow-shoe rabbits continue to be as abundant periodically as they have been in the past, control measures will be essential for the success of plantations in brushy areas in northern Minnesota and adjacent Wisconsin. The United States Biological Survey (Cox, 1911) suggested a method of poisoning to control the rabbits, but when the cost of control is added to the cost of planting and maintenance it may well be questioned whether planting is advisable on large areas of the aspen type.

Poor planting stock and careless planting may be causes of loss in any planting operation. They are, however, avoidable. The planting stock obtainable from the state nurseries in Wisconsin and Michigan or from reputable dealers is usually received in good condition. If the roots are kept moist and the trees are planted promptly, there should be little loss from poor stock. Careless planting can be reduced to a minimum by competent supervision and instruction of a planting crew by a man experienced in forest planting.

Planting Practice

White pine and white spruce are recommended as most desirable for planting on aspen sites. They may be planted either in the spring from the time the frost is out of the ground until June 1, or in the fall from about September 15 to the end of October. There are examples of spring and fall planting in the region, both showing excellent results.

Several classes of nursery stock of white pine, including 2-0, 3-0, 4-0, 1-2, 2-1, and 2-2,[6] have been tried. The 3-0, 1-2, and 2-1 may be recommended. The 3-0 stock is the least expensive of the classes that may be depended on to be satisfactory. In experiments at Cloquet, Minnesota (Hansen, 1927), 1-2 and 2-0 stock gave best results. In general, however, 2-0 stock must be of exceptionally high quality to give satisfactory results.

Transplant stock is generally considered essential with white spruce. White spruce planting on a large scale in Ontario, north of Sault Ste. Marie, on open sites cut over for pine and spruce 14 years before planting and badly burned since, has survived 83 to 85 per cent. The work was done by a private company, using 4-year-old transplant stock at a cost of about $12 per thousand trees planted.[7] This record is more favorable than is that of the earlier experience in Minnesota. Further experiments may demonstrate that 3-0 stock can be used. Lacking definite evidence, 2-1 or 2-2 stock of white spruce is recommended.

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[6] The first figure represents the number of years in the seedbeds; the second, years in the transplant beds. Thus, 3-0 is 3-year seedling stock.

[7] Information furnished through the courtesy of B. F. Avery, Forester of the Spanish River Pulp and Paper Mills.

Methods of planting.—Methods suitable for use in planting aspen lands may be grouped into two classes—slit and hole methods. In the hole method a hole large enough to hold the outspread roots of the tree is dug with a spade, mattock, or grub hoe, the tree is held in place, and the earth is filled in around the roots. Two men are ordinarily required, one to dig the holes and the other to set the trees and fill in the earth about the roots. The method is satisfactory almost any place where planting can be done. Objections to it are that it is slow and expensive and the earth has a tendency to settle and form depressions around the seedlings. These depressions, in underplantings of aspen, collect the aspen leaves, which may bury the seedlings.

The slit method consists in opening a slit with a spade or a special wedge-shaped planting iron with a handle. The roots of the tree are inserted in the slit and the opening about the roots is closed with another thrust of the blade. The man who makes the slit plants the tree. This method is rapid and inexpensive and has given satisfactory results. It is not adapted, however, to rocky or shallow soils. On these the hole method or direct seeding may have to be used. Detailed descriptions of the methods and tools, and directions for planting are given in several other publications (Cox, 1911, Hansen, 1927, Kittredge, 1928). Examples of highly successful plantations on aspen lands by both these methods or modifications of them in different parts of the Lake States testify to their usefulness.

In order to assure a good yield from the planted conifers, 500 to 800 trees to the acre, if possible, should be set out. This is less than is usually recommended for open sites, because in underplanting it is desirable to avoid placing the planted trees too close to large trees or clumps of brush already established. In dense stands of aspen, the number may have to be reduced to 300 or 400 to the acre. The planted trees should be spaced about 6 feet apart each way where brush and larger trees do not interfere. Obviously, in dense stands no uniform system of spacing can be followed. With 400 trees to the acre and allowing for a possible loss of 20 to 50 per cent during the early life of the plantation, more than 200 trees to the acre would be left. This should be sufficient to provide a good yield at maturity.

There are large areas of comparatively inaccessible stands of aspen that it will not be feasible to plant completely for many years and that have not enough coniferous seed trees to promise effective natural conversion. These areas may be converted gradually and at less cost by partial planting in strips or groups. Under one system the trees are planted in strips of 5 to 20 rows and an area of equal or greater width is left unplanted. Another strip of 5 to 20 rows is planted on the far side of the unplanted strip. In this way the cost of planting for the area as a whole may be reduced to half or less. These strips, in time, should form a stand of conifers sufficient to provide a merchantable crop. Before they are cut they may be expected to bear seed and reproduce naturally on the intervening unplanted strips. Incidentally, if the aspen is logged before the conifers are, the logging may be laid out so that most of the roads and skidding trails are in the unplanted strips, thus minimizing the damage to the conifers in the planted strips. The second system of partial planting may be called group planting. From 10 to 100 trees would be included in a group and the groups spaced 200 to 500 feet apart. The object and results of group planting would be similar to those for strip planting. If the groups were more widely spaced, the cost for the area could be reduced, with a correspondingly lower or longer deferred return from the planting.

Results in Plantations on Aspen Lands

Good survival has been obtained in a large proportion of the white pine and Norway pine plantations on aspen lands in Michigan and Wisconsin. The figures for Minnesota plantations are not quite so favorable because damage by rabbits has been much more severe here. The results are shown below in tabular form.

PERCENTAGE OF PLANTATIONS GROUPED ACCORDING TO SURVIVAL

Survival group	Survival per cent	White pine	Norway pine	Norway spruce
Good	60 or more	47	16	33
Medium	30 to 60	47	16	33
Poor	30 or less	10	10	34
Basis, number of plantations.......		40	19	6

The only one of the 19 Norway pine plantations with more than 0.45 crown density of aspen-birch had the lowest survival, 12 per cent. The three plantations of white spruce in Minnesota had 11, 24, and 32 per cent survival, respectively, and correspondingly poor growth owing largely to damage by rabbits. They should not, therefore, be considered representative of the results that may be expected with white spruce where it has a fair chance.

The average annual height growth in plantations 5 to 15 years old was 0.29 foot for white pine, 0.31 for Norway pine, and 0.28 for Norway spruce. The most rapid annual growth among the white pine plantations was 0.61 foot under 0.6 cover of aspen, and the best for Norway pine, 0.59 under 0.4 cover.

The results in existing plantations are not discouraging except in the brushy rabbit-infested areas of northern Minnesota.

Costs of Planting

The rate of planting aspen areas with white pine or white spruce, as already described, should be between 300 and 1,000 trees per man per day. Allowing $5.00 per 1,000 trees for the nursery stock and supervision, the total cost of planting 700 trees to the acre would be between $6.50 and $10. Thick brush or rocky sites might easily raise the cost to $15 or even $20 an acre. On the other hand, lower costs would be possible on sites easy to plant or if fewer trees to the acre were planted. It is estimated that a large proportion of the aspen lands could be planted for about $8.00 an acre.

ADVANTAGES OF ASPEN AND CONIFEROUS STANDS

Stands of aspen in the limited areas where it is marketable for $1.00 a cord or more, yield from 10 to 20 cords to the acre in 40 or 50 years. It may be expected, therefore, to return from 3 to 4 per cent compound interest on the investment and carrying charges. In other words, even the aspen that is favorably located will pay only a low profit as a timber growing enterprise. Low yields have been intentionally assumed in the foregoing statement to allow for the considerable areas where aspen stands are sufficiently open for the development of either natural or planted pine and spruce.

Pine and spruce under or mixed with the aspen will require from 60 to 100 years to become merchantable. They will, therefore, grow for 20 to 50 years after the aspen is cut. If the yield of 12 cords to the acre of white spruce at 100 years, previously quoted from Kenety (1917), is taken as an example, a calculation may be made of the advantages of natural conversion. Assuming taxes at 10 cents an acre and protection at 3 cents an acre, for a 50-year period after the aspen is cut, the spruce with a stumpage value of $6.05 per cord would earn 6 per cent on the investment, at $4.01 would earn 5 per cent, and at $2.67 would earn 4 per cent compound interest. The future values of spruce stumpage will almost certainly be as high as those indicated or higher, so the spruce resulting from the natural conversion of aspen will earn 5 or 6 per cent profit or more.

Under similar circumstances, white pine yielding 5,000 board feet to the acre would have to have stumpage values of $14.53 to earn 6 per cent, of $9.63 to earn 5 per cent, and of $6.42 to earn 4 per cent. Again, these values are hardly more than the present stumpage values of white pine in the region. There is, therefore, ample justification for fire protection and encouragement of timber growing on aspen areas with natural white spruce or white pine in the attractive returns to be anticipated from the spruce or pine even when they produce only conservatively low yields to the acre.

On the large areas where planting will be necessary, the prospect is less favorable. Planting may be expected to cost, on the average, $8.00 an acre. Again assuming that the aspen will carry the annual expenses for the first 40 or 50 years, there remain the charges for the 20 to 50 years after the aspen is cut and before the pine and spruce are merchantable, plus the interest on the planting investment of $8.00 an acre over the 60- to 100-year rotation of the pine or spruce. Planted stands of white pine on aspen areas may reasonably be expected to yield 10,000 board feet to the acre at 80 years, and 20,000 board feet at 100 years. The corresponding yields for white spruce would be 20 cords at 80 years and 35 cords at 100 years. The stumpage values that the pine or spruce would have to have under these conditions to earn different percentages on the costs and investment, are shown in the following table.

Interest, per cent	White Pine		White Spruce	
	Yields		Yields	
	10,000 board feet in 80 years	20,000 board feet in 100 years	20 cords in 80 years	35 cords in 100 years
	Future stumpage values			
6	$91.90	.....	$45.95	.....
5	48.46	$55.01	24.23	$31.43
4	21.65	21.80	10.82	12.46

The stumpage values are comparable with those in sales at the present time, only at 4 per cent interest. Greater returns are dependent on the possible speculative rises in stumpage values during the next 40 or 50 years, which are not impossible or even unlikely in view of the decreasing supply of spruce and white pine.

SUMMARY

To sum up, aspen grows rapidly and produces large volumes of wood in 40 to 50 years. It will probably return 4 to 5 per cent interest on the investment, even at very moderate stumpage prices, and it is easily managed. The aspen is therefore an excellent timber crop for an industry that can use it to advantage or for any owner so located that he can sell it readily. Few owners of aspen land, however, are now so situated.

The majority of owners, who can see no likelihood of using or selling their aspen and face the prospect that much of the oncoming crop will rot on their hands, should consider conversion to pine and spruce. The encouragement of natural conversion can almost always be justified on the ground of economic advantage and profit. Artificial conversion by planting, which involves an investment of $8.00 an acre, more or less, may return not more than 4 per cent on the investment. The planting is, therefore, advisable chiefly for public agencies and for private industries that need the pine or spruce and are willing to forego a high rate of interest on the timber-growing part of the business in order to maintain the manufacturing part and the higher profits derivable from it.

From the viewpoint of public welfare, a future supply of conifers is more needed than a supply of aspen. Conversion of aspen to conifers should, therefore, be encouraged, both by assistance to private owners of aspen lands in the conversion of their lands to conifers and by the initiation by public agencies of measures to promote the conversion on publicly-owned lands. On lands already publicly-owned, public agencies can well afford to invest funds in long-term timber-growing enterprizes that will yield 4 per cent. States, counties, and the federal government may also acquire additional aspen lands that would not otherwise be converted, as a partial solution of the problem.

What is the probable solution for the whole 21,000,000 acres of aspen-birch lands in the northern Lake States? Perhaps 20 per cent is being converted to conifers naturally. Possibly 30 per cent may be marketable for the aspen and birch on their own merits. It may be that 20 per cent of the area will be planted and converted by private owners during the next few decades, altho such a movement has hardly begun. The aspen on the remaining 30 per cent, including more than 6,000,000 acres, will deteriorate and go to waste unless steps are taken to prevent it. Two possible measures may be suggested: (1) The acquisition and planting of aspen lands by public agencies; (2) the dissemination of information as to the abundant supply of aspen, its value for present forms of utilization, and study of its properties for the purpose of developing new uses.

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APPENDIX

Volume Tables for Aspen and Paper Birch

TABLE XIII

SECOND GROWTH ASPEN
(*Populus tremuloides* Michx.)
Minnesota

Gevorkiantz, S. R. 1926 Total cubic feet

Diameter breast high	Total height of tree—feet															Basis
	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	
Inches	Total volume—cu. ft.															Trees
2	.26	.31	.37	.42												31
3	.57	.69	.80	.92	1.0	1.1	1.3									74
4	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6							84
5	1.6	1.9	2.2	2.5	2.8	3.1	3.4	3.7	4.0	4.3						74
6		2.7	3.1	3.5	4.0	4.4	4.9	5.3	5.8	6.2	6.6					61
7				4.8	5.4	6.0	6.6	7.2	7.8	8.3	8.9	9.5	10.1			42
8				6.2	7.0	7.7	8.5	9.3	10.0	10.8	11.6	12.4	13.1			47
9						9.7	10.7	11.6	12 6	13.6	14.5	15.5	16.5			38
10						11.9	13.1	14.3	15.4	16.6	17.8	19.0	20.2	21.4		36
11							15.7	17.1	18.6	20.0	21.4	22.9	24.3	25.7		24
12								20.2	21.9	23 6	25.3	27.0	28.7	30.4		27
13									25.6	27.6	29.6	31.6	33.5	35.5	37.5	23
14										31.9	34.1	36.4	38.7	41.0	43.3	18
15										36.4	39.0	41.6	44.2	46.8	49.4	5
16										41	44	47	50	53	56	
Basis	9	20	47	52	63	63	43	44	43	33	38	47	57	24	1	584

Volume includes stump, stem, and top without bark
Compiled by the form factor method from data collected by E. E. Probstfield in 1925.
Cubed in 8-foot sections by Smalian's formula. A. F. Verrall assisted in compilation.
Block indicates extent of original data.
Difference between total volume of trees used as a basis and volumes as taken from the table, +0.08 per cent.
Average deviation of individual tree volumes from interpolated tabular volumes, ±5.33 per cent.

TABLE XIV
SECOND GROWTH ASPEN
(*Populus tremuloides* Michx.)
Minnesota

Gevorkiantz, S. R. | 1926 | Merchantable cubic feet

Diameter breast high	Total height of tree—feet														Basis
	30	35	40	45	50	55	60	65	70	75	80	85	90	95	
Inches	Merchantable volume—cu. ft.														Trees
4	.58	.76	.93	1.1	1.3	1.5	1.6	1.9							84
5	1.3	1.5	1.8	2.2	2.5	2.8	3.1	3.4	3.7						74
6	2.2	2.5	2.9	3.4	3.8	4.2	4.7	5.2	5.6	6.1					61
7			4.2	4.8	5.4	5.9	6.5	7.2	7.8	8.4	8.9	9.5			42
8			5.6	6.3	7.0	7.8	8.6	9.4	10.2	11.0	11.7	12.5			47
9					8.9	9.9	10.8	11.8	12.8	13.8	14.8	15.8			38
10					11.0	12.2	13.4	14.6	15.8	17.0	18.2	19.4	20.6		36
11						14.7	16.2	17.6	19.1	20.5	22.0	23.4	24.9		24
12							19.2	20.9	22.6	24.4	26.1	27.7	29.5		27
13								24.5	26.5	28.5	30.5	32.4	34.4	36.4	21
14									30.7	33.0	35.2	37.5	39.8	42.1	18
15									35.1	37.7	40.2	42.8	45.4	48.0	5
16									40	43	46	49	52	55	
Basis		4	25	57	63	43	44	43	33	38	47	57	23	1	477

Volumes inside of bark.
Stump height, 1 foot; top diameter inside of bark, 3 inches.
Compiled by expressing merchantable volume as a percentage of the total volume.
Data collected in 1925 by E. E. Probstfield. A. F. Verrall assisted in the compilation.
Difference between total volume of trees used as a basis and volumes as taken from the table, —0.16 per cent.
Average deviation of individual tree volumes from interpolated tabular volumes, ±6.05 per cent.
Block indicates extent of original data.

TABLE XV

SECOND GROWTH ASPEN

(Populus tremuloides)

Minnesota

Gevorkiantz, S. R. 1926 International ⅛ inch kerf.

Diameter breast high	1	1½	2	2½	3	3½	4	4½	Basis
Inches	Volume—bd. ft.								Trees
6	15	20	26	31					43
7	15	24	32	40					42
8	15	27	39	50	60				47
9	15	30	44	58	74	90			37
10		34	51	68	86	104	122		36
11		37	58	79	100	120	144	167	22
12		41	66	92	118	144	171	198	26
13			75	106	138	170	202	233	23
14			86	123	161	199	237	274	18
15				142	186	230	276	319	5
16				163	213	264	319	369	
Basis	36	36	32	35	44	39	68	9	299

Stump height, 1 foot; top diameter inside of bark, 5 inches; trees scaled in 16-foot lengths.

Compiled by the Frustum Form Factor method from data collected by E. E. Probstfield. A. F. Verrall assisted in the compilation.

Difference between total volume of trees used as a basis and volumes as taken from the table −0.13 per cent.

Average deviation of individual tree volumes from interpolated tabular volumes, ±5.33 per cent.

Block indicates extent of original data.

TABLE XVI

SECOND GROWTH ASPEN

(Populus tremuloides)

Minnesota

Gevorkiantz, S. R. 1926 Scribner Decimal C.

Diameter breast high	Number of 16-foot logs								Basis
	1	1½	2	2½	3	3½	4	4½	
Inches	Volume—bd. ft.								Trees
7	2	3	4	6					20
8	2	3	4	6	7				47
9	2	3	5	6	8	9			37
10		3	5	7	8	10	12		36
11		4	6	7	9	11	13	15	22
12		4	6	8	10	13	15	17	26
13			7	9	12	14	17	20	23
14			8	11	14	16	19	23	18
15				12	15	19	22	26	5
16				14	17	22	26	30	
Basis	22	34	27	45	25	45	35	1	234

Stump height, 1 foot; top diameter inside of bark, 6 inches. Scaled in 16-foot lengths.

Compiled by the Frustum Form Factor method from data collected in 1925 by E. E. Probstfield. A. F. Verrall assisted in the compilation.

Difference between total volume of trees used as a basis and volumes as taken from the table, +0.35 per cent.

Average deviation of individual tree volumes from interpolated tabular volumes, ±6.[illegible]8 per cent.

Block indicates extent of original data.

TABLE XVII
ASPEN
(Populus tremuloides)
Minnesota

Gevorkiantz, S. R. 1928 Cords per tree

Diameter breast high	Total height of tree—feet														Cubic feet of wood per cord
	30	35	40	45	50	55	60	65	70	75	80	85	90	95	
Inches	Peeled volume—cords														
4	.010	.013	.016	.019	.022	.026	.028	.032							58
5	.021	.025	.028	.035	.040	.045	.050	.055	.060						61
6	.034	.039	.045	.053	.060	.066	.073	.081	.088	.095					64
7			.062	.070	.079	.087	.096	.11	.11	.12	.13				68
8			.078	.089	.099	.11	.12	.13	.14	.15	.16	.17			71
9					.12	.13	.14	.16	.17	.18	.20	.21			74
10					.14	.16	.17	.19	.21	.22	.24	.26	.27		76
11						.19	.21	.23	.25	.26	.28	.30	.32		78
12							.24	.26	.28	.31	.33	.35	.37		79
13								.30	.33	.35	.38	.40	.43	.45	80
14									.37	.40	.43	.46	.48	.51	82
15									.42	.45	.48	.51	.54	.57	84
16									.47	.51	.54	.58	.61	.65	85

Standard cords, 4x4x8 feet.

Volume of peeled stem above a one-foot stump to a top diameter inside of bark, 3 inches.

Compiled from the merchantable volume in cubic feet by dividing the volume per tree by the number of cubic feet per cord for each diameter.

Eleven stacks of closely piled wood were measured to establish the relation between cubic feet and cords.

Wood was cut in 8-foot lengths and piled. Converting factors, cubic feet per cord, give volume inside bark in each cord of unpeeled wood.

Basis was 477 trees distributed as in the table of merchantable cubic feet.

Block indicates extent of original data.

TABLE XVIII
SECOND GROWTH PAPER BIRCH
(Betula papyrifera)
Lake States

Gevorkiantz, S. R. 1926 Cubic feet

Diameter breast high	Total height of tree—feet										Basis
	25	30	35	40	45	50	55	60	65	70	
Inches	Total volume—cu. ft.										Trees
2	.28	.34	.40	.46							17
3	.61	.74	.86	.98	1.1	1.2					21
4	1.1	1.3	1.5	1.7	1.9	2.1	2.3				21
5		1.9	2.3	2.6	2.9	3.2	3.6	3.9			18
6		2.7	3.2	3.6	4.1	4.5	5.0	5.5	5.9		14
7			4.2	4.9	5.5	6.1	6.7	7.3	7.9	8.5	13
8					7.0	7.7	8.5	9.3	10.1	10.8	8
9					8.6	9.6	10.6	11.5	12.5	13.5	3
10						11.7	12.8	14.0	15.2	16.3	1
Basis	1	18	13	15	18	18	12	18	2	1	116

Volume includes stump, stem, and top without bark.

Compiled by the Form Factor method from data collected in 1926.

Cubed in 8.15-foot sections by Smalian's formula.

Block indicates extent of original data.

Difference between total volume of trees used as a basis and volumes as taken from the table, —0.06 per cent.

Average deviation of individual tree volumes from interpolated tabular volumes, ±4.01 per cent.

TALE XIX
SECOND GROWTH PAPER BIRCH
(Betula papyrifera)
Lake States

Gevorkiantz, S. R. 1926 Merchantable cubic feet

Diameter breast high	Total height of tree—feet								Basis
	35	40	45	50	55	60	65	70	
Inches	Merchantable volume—cu. ft.								Trees
4	.69	.92	1.2	1.4	1.7				21
5	1.5	1.9	2.2	2.6	3.0	3.3			18
6	2.5	3.0	3.5	4.0	4.4	4.9	5.3		14
7	3.6	4.2	4.8	5.5	6.1	6.7	7.3	7.9	13
8		5.6	6.4	7.1	7.9	8.7	9.5	10.3	8
9			8.0	9.0	9.9	10.9	11.9	12.8	3
10				11.0	12.2	13.4	14.5	15.7	1
Basis	1	9	17	18	12	18	2	1	78

Volume inside of bark.

Stump height, one foot; top diameter inside of bark, 3 inches.

Compiled by expressing merchantable volume as a percentage of the total volume.

Data collected in 1926.

Difference between total merchantable volume of trees used as a basis and volumes as taken from the table, +0.19 per cent.

Average deviation of individual tree volumes from interpolated tabular volumes, ±7.7 per cent.

Block indicates extent of original data

TALE XX
SECOND GROWTH PAPER BIRCH
(Betula papyrifera)
Lake States

Gevorkiantz, S. R. 1926 Cords

Diameter breast high	Total height of tree—feet								Basis
	35	40	45	50	55	60	65	70	
Inches	Peeled volume—cords								Trees
4	.01	.01	.02	.02	.02				21
5	.02	.02	.03	.03	.04	.04			18
6	.03	.04	.04	.05	.05	.06	.07		14
7	.04	.05	.06	.06	.07	.08	.09	.09	13
8		.06	.07	.08	.09	.10	.11	.12	8
9			.09	.10	.11	.12	.13	.14	3
10				.12	.13	.14	.15	.16	1
Basis	1	9	17	18	12	18	2	1	78

Standard cords, 4x4x8 feet.

Volume of peeled stem above a one-foot stump to a top diameter inside of bark, 3 inches.

Compiled from the merchantable volume in cubic feet by dividing the volume per tree by the number of cubic feet per cord for each D.B.H. class by the use of cordwood factors from U. S. Forest Service Circular 163 converted to D.B.H. basis.

Data collected in 1926.

Block indicates extent of original data.

Common and Scientific Names of Trees Mentioned in Text

Common Name	Scientific Name
American elm	*Ulmus americana,* Linnaeus
Aspen	*Populus tremuloides,* Michaux
Balsam fir	*Abies balsamea,* (Linnaeus) Miller
Balsam poplar	*Populus balsamifera,* Linnaeus
Basswood	*Tilia Glabra,* Ventenat
Black ash	*Fraxinus nigra,* Marshall
Black spruce	*Picea Mariana,* (Miller) Britton, Sterns, and Poggenberg
Bur oak	*Quercus macrocarpa,* Michaux
Eastern hemlock	*Tsuga canadensis,* (Linnaeus) Carriers
Green ash	*Fraxinus pennsylvanica lanceolata,* (Borkhausen) Sargent
Hop-hornbeam	*Ostrya virginiana,* (Miller) Koch
Jack oak	*Quercus ellipsoidalis,* E. J. Hill
Jack pine	*Pinus banksiana,* Lambert
Large-tooth aspen	*Populus grandidentata,* Michaux
Northern white cedar	*Thuja occidentalis,* Linnaeus
Northern white pine	*Pinus strobus,* Linnaeus
Norway pine	*Pinus resinosa,* Solander
Norway spruce	*Picea abies,* Karst
Paper birch	*Betula papyrifera,* Marshall
Pin cherry	*Prunus pennsylvanica,* Linnaeus fils
Red maple	*Acer rubrum,* Linnaeus
Red oak	*Quercus borealis,* Michaux
Red spruce	*Picea rubra,* Link
Scarlet oak	*Quercus coccinea,* Muenchhausen
Scotch pine	*Pinus sylvestris,* L.
Sugar maple	*Acer saccharum,* Marshall
Tamarack	*Larix laricina,* (DuRoi) Koch
Western white pine	*Pinus monticola,* D. Don
White spruce	*Picea glauca,* (Moench) Voss
Yellow birch	*Betula lutea,* Michaux

Common and Scientific Names of Shrubs and Herbaceous Vegetation Mentioned in the Text

Common Name	Scientific Name
Alder	*Alnus incana,* (L.) Moench.
Arbutus	*Epigaea repens,* L.
Bedstraw	*Galium boreale,* L.
Bellwort	*Uvularia grandiflora,* Sm.
Baneberry	*Actaea rubra,* (Ait.) Willd.
Blueberry	*Vaccinium pennsylvanicum,* Lam.
Brake fern	*Pteris aquilina,* L.
Canada mayflower	*Maianthemum canadense,* Desf.
Choke cherry	*Prunus virginiana,* L.
Clintonia	*Clintonia borealis,* Ait.

Clubmoss	*Lycopodium spp.,* not *complanatum,* L.
Dwarf raspberry	*Rubus triflorus,* Richards
Dogwood	*Cornus paniculata,* L'Her.
	Cornus circinata, L'Her.
Early meadow rue	*Thalictrum dioicum,* L.
Fern	*Asplenium filix-femina,* (L.) Bernh.
	Aspidium spinulosum, (O. F. Muller) Sw.
	Osmunda claytoniana, L.
Gooseberry	*Ribes spp.*
Ground pine	*Lycopodium complanatum* var. *flabelliforme,* Fernald
Hazel	*Corylus americana,* Walt.
	Corylus rostrata, Ait.
Hepatica	*Hepatica acutiloba,* DC.
Large leafed aster	*Aster macrophyllus,* L.
Mountain maple	*Acer spicatum,* Lam.
Mitrewort	*Mitella nuda,* L.
Pyrola	*Pyrola secunda,* L.
	Pyrola rotundifolia, Man. ed. 6, not L.
Raspberry	*Rubus idaeus* var. *aculeatissimus* (C. A. Mey) Regel and Tiling
Starflower	*Trientalis americana,* (Pers.) Pursh.
Sweet fern	*Myrica asplenifolia,* L.
Twisted-stalk	*Streptopus roseus,* Michx.
Viburnum	*Viburnum dentatum,* L.
	Viburnum opulus L. var. *americanum* (Mill) Ait.
Wild ginger	*Asarum canadense,* L.
Wintergreen	*Gaultheria procumbens,* L.